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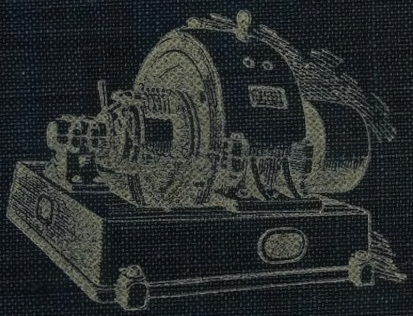

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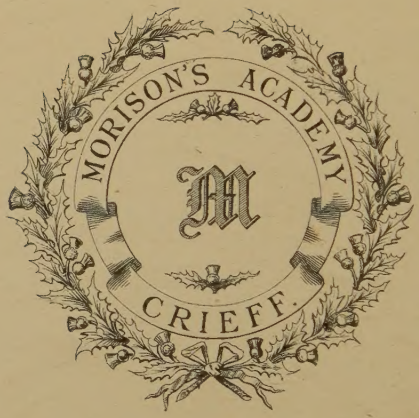

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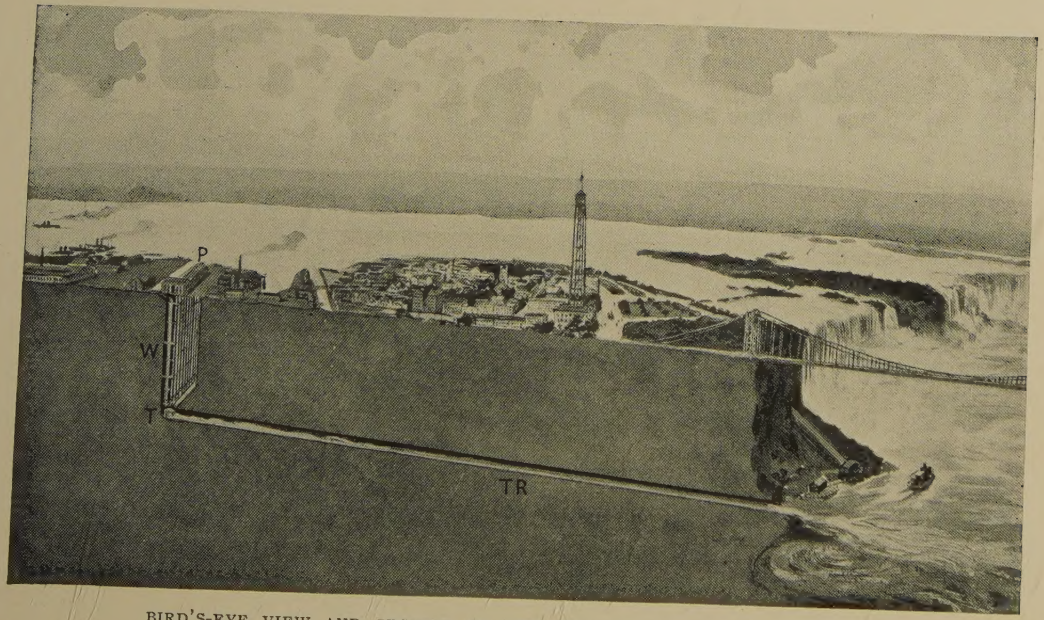

BIRD'S-EYE VIEW AND SECTION OF THE NIAGARA INSTALLATION.—*See p. 267*

(*After Cassier's Magazine*)

POPULAR ELECTRICITY

BY

WALTER HIBBERT

F.I.C., F.C.S., A.M.I.E.E.

LECTURER ON PHYSICS AND ELECTRO-TECHNOLOGY AT THE REGENT STREET POLYTECHNIC

WITH ABOUT 200 ILLUSTRATIONS

CASSELL AND COMPANY, LIMITED

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PREFACE

So many industrial occupations are now invaded by electrical methods that a certain familiarity with the surface working is quite common. Popular interest has therefore deepened, and requires more detail for its satisfaction than was formerly the case. This volume is written for those who would like to know more than is commonly offered to them, and gives a bird's-eye view of the many applications of electric energy.

In drawing the majority of the diagrams for this book I have been guided by a desire to illustrate the principles involved rather than to show the external appearance.

I am indebted to the following for permission to use various illustrations :—*Cassier's Magazine*, The Electrician Co., General Electric Co., Griffin & Co., Hart Accumulator Co., Longmans & Co. (Fleming's "Wave Telegraphy"), Isenthal & Co., Newton & Co., Prometheus Co., and Messrs. Spon (Allsopp's "Electric Bells"). Some of the diagrams have been obtained from Walmsley's "Electricity in the Service of Man," and Ayrton's "Practical Electricity."

W. HIBBERT.

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POPULAR ELECTRICITY

CHAPTER I

INTRODUCTION

THIRTY years ago popular electricity consisted of a series of showy experiments, in which sparks and light played a large part. To-day its practical applications are so numerous and so brilliant that the attitude of mind towards the subject has totally changed. There are a widespread interest and an almost equal curiosity to inquire into the causes of these remarkable developments; to get below the surface. Yet the books hitherto provided are not quite suitable. They are either too technical—adapted for professional engineers—or else they are too superficial, failing to give enough information to satisfy an intelligent reader.

In the following pages an effort is made to explain the principles underlying well-known electrical appliances. It is assumed that the reader wishes to know how electricity is made to warm and light the house; how a dynamo or battery is able to do work; how telegraphy and telephony are accomplished; and how tram-cars and electric automobiles are propelled. It is also assumed that he wishes to know what science says as to the meaning of electricity. We therefore begin with a short sketch of the foundations on which electric work now depends, passing quickly from the

simplest and oldest to the most recent experiments, leading up to a short statement of the prevailing ideas about electrons.

Experimental Foundations — Electrical.—These may be stated very briefly :—

EXPERIMENT I.—*Meaning of Electricity.*—Let a glass tube be rubbed by a silk pad and then brought near any light substance, such as the pith ball in Fig. 1. The glass will attract the ball.

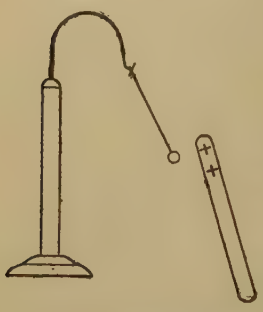


Fig. 1.—Rubbed glass attracting pith ball.

A rod of sealing-wax rubbed by flannel shows similar attractive force.

Both glass and wax are said to owe their new power to a charge of electricity now appearing on their surfaces, and made evident by the friction. So far as these experiments go, the electricity on the glass is identical with that on the sealing-wax, or with that on amber when rubbed as in the ancient Greek experiment. The name Electricity is derived from "elektron," the Greek name for amber.

Thousands of experiments have proved that when proper precautions are taken, every material body behaves like glass, sealing-wax, or amber; that is, it shows this power of attraction after being rubbed.

EXPERIMENT II.—*Two Kinds of Electricity.*—When two glass tubes are rubbed by silk, and the rubbed ends brought near, as in Fig. 2, they *repel* each other.

When two rods of sealing-wax are rubbed by flannel and treated in a similar way, they also *repel* each other.

Yet an electrified glass tube attracts an electrified rod of sealing-wax. In brief:—

Electrified glass *repels* electrified glass.

Electrified sealing-wax *repels* electrified sealing-wax.

But electrified glass *attracts* electrified sealing-wax.

These three facts prove that the electricity on the glass is different from that on the sealing-wax: *There are two kinds of electricity.* Now experience shows that these two kinds can be obtained from any and every known material body. We can get both kinds from glass; we can get both kinds from sealing-wax; we can, in fact, by appropriate choice of rubber, get either kind from paper, wood, iron, stone, rock, or water. Every known substance contains both kinds of electricity.

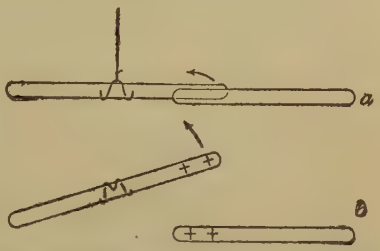


Fig. 2.—Repulsion of two electrified glass rods.

a, elevation; *b*, plan.

Seeing that this is so, it becomes necessary to distinguish one kind from the other, else there will be perpetual confusion. To prevent this, the kind found on glass rubbed by silk is called "positive," and that found on sealing-wax rubbed by flannel is called "negative." The names are given for convenience, and for convenience only. They have no other significance.

It is a point of primary importance to realise that positive and negative electricity have opposite

characters. However they are obtained, each kind repels itself, each kind attracts the other. It is in this opposition or contrariety that we find the solution of so many problems. Take, for example, the question: Why or how does friction produce these two electricities? The answer is, that it does not produce them: it separates them. We shall anticipate a little, in order to clear up this point. Fig. 3 will help in this. S and G are diagrams of the silk and glass, the simple straight outline being chosen to make the electrical part clear. A small portion at the top of each is marked with + and − signs to suggest that they both contain positive and negative electricity. Before rubbing, as in S_1 and G_1, these kinds of electricity are equal in quantity and evenly mixed. Therefore because of their opposite properties, they cannot be detected. After rubbing, as in S_2 and G_2, the rubbed surfaces *a* and *b* have exchanged some of their charges. There is the same quantity of each kind as before, but G_2 has now an excess of positive, S_2 an excess of negative. The *excess* can now make its presence and action felt.

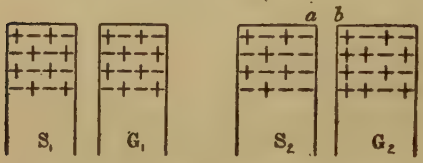


Fig. 3.—Diagram of electricity in silk and glass.

S_1 and G_1 before rubbing, S_2 and G_2 after rubbing.

Thus the electricity has not been *produced;* it has been distributed in a different way; that is, an unsymmetrical way. Each has gained what the other has lost. An electrified body means one with a surplus of one kind of electricity.

According to this, any two substances rubbed to-

gether ought to be equally and oppositely electrified, and this is always found to be the case. It is impossible to obtain a quantity of positive electricity without at the same time getting an equal quantity of negative. The silk pad is always charged negatively after being used to rub glass. It is not until the glass and silk are separated that their charges can be detected.

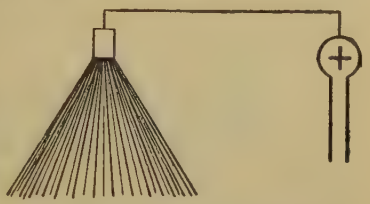


Fig. 4.—Repulsion of electrified paper tassel.

Further proof of these ideas will arise in the next experiment. Meanwhile notice that when a body is charged with an excess of either kind of electricity, its parts repel each other; if any of these parts are light, they will move apart (Fig. 4).

Experiment III.—*Friction not necessary.*—Two insulated conductors C_1 C_2 are connected by a thin wire

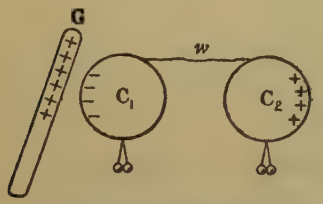


Fig. 5.—Two spheres under the influence of an electrified glass rod.

Fig. 6.—Equal and opposite charges obtained as the result of influence.

w (Fig. 5). A pair of pith balls hangs from each conductor, so as to indicate by their repulsion when they are electrified. At first they lie together; there is no

sign of electrification. A charged glass tube G is now brought near C_1, and, *while it is there,* the connecting wire *w* is removed by a sealing-wax handle (this is to prevent leakage). The glass tube G is then removed. The pith balls now show that both C_1 and C_2 are electrified (Fig. 6). Neither of them has been rubbed or touched in any way, so that their charges are not due to friction. Experiment shows that the charge on C_1 is negative, that on C_2 is positive. If the balls are allowed to touch, all signs of electricity disappear, a proof that their charges were of opposite kinds and equal. These results are easy to explain if we assume that C_1 C_2 originally contained both kinds of electricity, and that similar electricity repels while dissimilar attracts. For when the glass tube is brought near C_1 its positive charge will act on the electricities in C_1 C_2, repelling some positive to C_2, attracting some negative to C_1; C_2 thus gets an excess of positive, C_1 an excess of negative, and whilst each has this excess, the connecting wire *w* is removed, so that when G is also removed the separated electricities cannot return. When the balls are touched the separated charges mix once more, and return to the normal state.

From this we learn that electricity can be evoked from these bodies *without friction.* Moreover, it disappears by a mere bringing together of the opposite kinds.

Experimental Foundations — Magnetic. — At certain places on the earth there is found a black stone which has the property of attracting iron. The stone is called magnetite, after the name of the place near to which it was found in ancient times (Magnesia, in Lydia, Asia Minor). When this stone is rubbed on steel, the latter becomes a magnet; that is, it acquires the same properties as the magnetite, and

can be more conveniently used for experimental purposes.

EXPERIMENT I.—Iron filings stick to a magnet, but not all over its surface. The regions of attraction

Fig. 7.—Magnet and iron filings.

are at and near the ends. In a well-made bar magnet they are always greatest at the ends (Fig. 7). The regions of attraction are called the *poles* of the magnet.

EXPERIMENT II.—A suspended or pivoted bar magnet sets itself in a definite line, which in the British Isles is practically north and south. The mariner's compass (Fig. 8) is founded on this property.

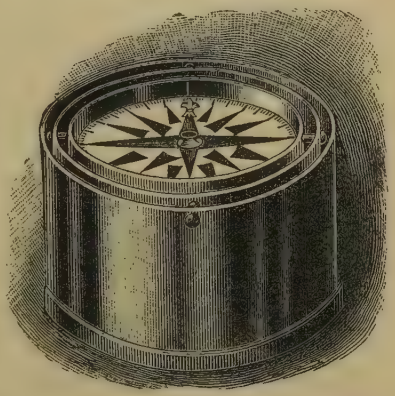


Fig. 8.—Mariner's compass.

There is a difference between the two ends or poles of the magnet: one end always turns northwards, the other southwards. If the needle be twisted round so as to reverse the ends and then be left to itself, it will not remain so, although it is in the same north and south line as before. It will turn through half a revolution, so that

the same pole as before points northwards. This pole is called the north (or the north-seeking) pole; the other is called the south (or the south-seeking) pole.

Experiment III.—Let two bar magnets be suspended and their north poles determined and marked. Then experiments show that:

(*a*) Two north poles repel.
(*b*) Two south poles repel.
(*c*) North and south poles attract.

These laws are similar to those of electricity, and seem to be still more akin when we find that the north and south poles of a given magnet are always equal to each other. It follows that if the two poles are near together they will neutralise each other.

Experiment IV.—If attempts be made to magnetise any ordinary material, such as copper, silver, wood, rock, etc., they fail. Besides iron and steel, the only things which can be magnetised are nickel, cobalt, and chromium. Even these three metals are much less potent as magnets than the best iron and steel.

Experiment V.—A bar of steel weighs exactly the same before and after magnetisation, so that no material is added or subtracted during the act: magnetisation of iron adds no weight to it.

The Invisible Magnetic Flux—What is Meant by a Magnetic Field.—We now come to a most extraordinary fact about magnets. Their effective value lies not in the steel itself so much as in the space round about it. There is a peculiar and invisible attachment to a magnet, if the word attachment can be allowed. The act of magnetisation not only alters the steel, but it alters the space round the steel. A mysterious magnetic flux is established between the

poles of the bar, and the region throughout which this flux is potent is called the "field" of the magnet.

EXPERIMENT VI.—If a magnet be covered by a sheet of cardboard on which iron filings have been sprinkled, and the cardboard be gently tapped, the filings will assume a series of beautiful curves (Fig. 9). The corresponding curves round the ends of a horse-shoe magnet are seen in Fig. 10. The curves extend from one pole to the other. They are quite intangible:

Fig. 9.—Magnetic curves round a bar magnet.

the hand can be moved through the strongest magnetic field without experiencing any resistance. Yet the space can be otherwise proved to be in a special state. For example, if a piece of copper be moved by hand through a very strong field, the experimenter feels that it is being resisted, as if going through soft cheese. Evidently, therefore, the iron filings in Fig. 9 are not themselves creating the lines; they are only revealing something otherwise unnoticed.

Careful experiment proves that the magnetic flux can be detected in the body of the steel as suggested in Fig. 11. This can be done by breaking the bar.

As soon as this is done, the flux is found between the two ends, the two new poles appear—one pole at

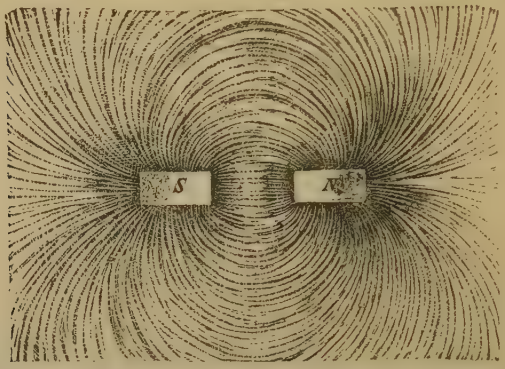


Fig. 10.—Magnetic curves round a horseshoe magnet.

each new end. Each of the parts into which the bar is broken has still two opposite poles, the one it had

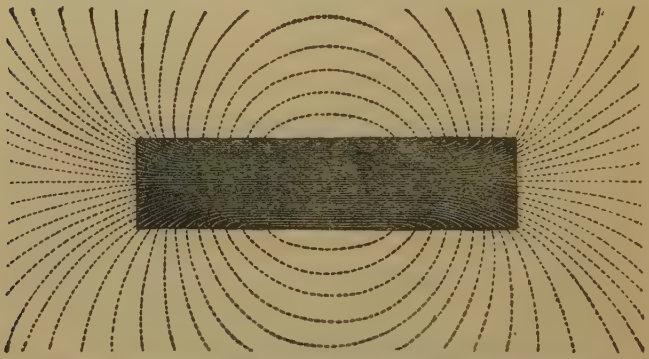


Fig. 11.—Magnetic flux traced inside the bar magnet.

originally and a new one of opposite name formed at the broken end.

These effects of breaking continue when the bar is broken into four, eight, or more pieces. Wherever a break is made, two poles spring into existence, having a magnetic flux between them. As there is no evidence of magnetisation at the middle of a long, well-magnetised bar, and yet the poles and field spring into existence as soon as this part is broken, it is reasonable to suppose that the two poles were in existence before the break, but so near that they neutralised each other.

This last point can be put in a different and much better way. No magnet can be detected except by working in its *field*. If, therefore, there are poles

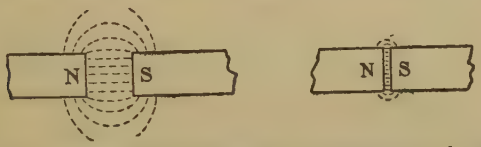


Fig. 12.—Range of field depends on separation of poles.

at the middle of a magnet before it is broken, the flux between these poles is confined to the minute regions between the atoms of steel, and into this minute region we cannot go to make experiment. The concentration of the flux between two poles is seen in Fig. 12. Two poles are shown at different distances. When near together the flux has a smaller range than when they are farther apart. When the poles practically touch, the field can only just be detected very near to the bar.

EXPERIMENT VII.—Rubbing is not necessary to produce magnetisation. A bar of unmagnetised iron or steel can be magnetised by being placed in the *field* of another magnet, especially if the length of the bar be put along the lines of the field. It follows from

this that each of the filings used in getting the curves has become a little magnet.

EXPERIMENT VIII.—A compass needle put down anywhere in a magnetic field sets itself along the local direction of the lines. It is by virtue of this fact that the filings have taken a different "set" at different places. They show what is called the changing direction of the field. The north pole of the needle always points along the line *away from* the north pole of the magnet.

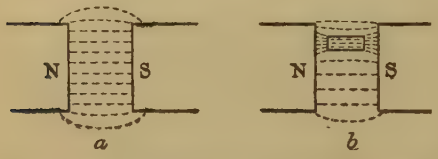


Fig. 13.—Concentration of field by iron.
a, without iron; *b*, with iron.

EXPERIMENT IX.—The lines of a magnetic field are affected by iron. They are concentrated by it. Fig. 13 indicates what is meant. The lines curl towards the iron and establish themselves along it as far as possible. They show a preference for the iron as compared with air. Iron is said to be more permeable to the lines than is air or any ordinary material.

Electric Field.—The great modern advances in electrical practice have taken place since Faraday recognised that an electrical charge had a *field*, of similar general character to that of a magnet, but differing in fundamental points. The existence of this electric field is not so easy to demonstrate, but it can be done. Light substances like sulphate of quinine are used instead of iron filings, and a glass plate instead of cardboard. Or a small aluminium or paper needle may be used, held in the middle by a silk thread. Fig. 14 shows the lines along which such a needle sets itself as it is taken round a charged sphere. The

set is always along radial straight lines. The difference between the fields round positive and negative charges is not in their form, but in their direction. Put a positive charge down at x in the field of Fig. 14, it will be driven *outwards*. If the sphere had a negative charge, the field would still have radial lines, but a positive charge would be drawn inwards. Arrows are therefore placed to show the direction of the field. These radial fields extend to very great distances. The electric field becomes weaker as the distance increases.

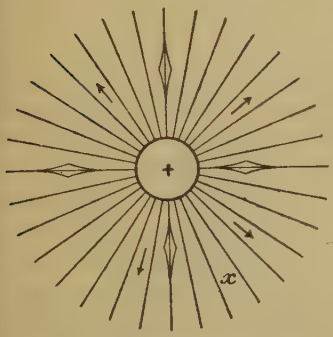


Fig. 14.—Electric field round an electrified sphere.

Fig. 15 shows the field round two unlike charges. The lines are no longer radial. Those from one charge curl round towards, and run into, those from the

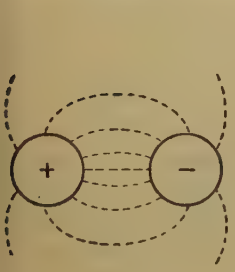


Fig. 15.—Electric field between + and − charges.

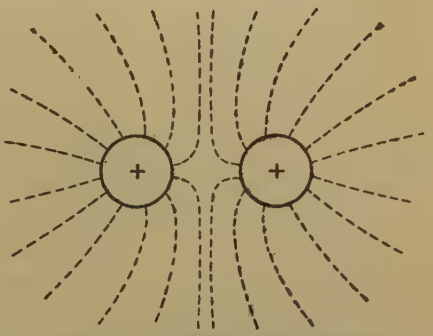


Fig. 15*a*.—Electric field between two similar charges.

other. Several consequences are to be noted. The fields of neither charge stretch as far as before,* and they are concentrated in the space between the two charges. The field *there* becomes more intense than before.

Fig. 15*a* is the field round two like charges, either two positives or two negatives. The charges and the flux are here concentrated on the *outer* surfaces of the spheres. This comes from the repulsion between the like charges, or rather from the effect of one part of the flux on its neighbour. One portion of a flux always repels another part of the same flux. The lines seem to exercise a lateral repulsion on each other. Electric fields act on every substance (Experiment III., p. 5), producing + and − charges by their influence.

Importance of the Magnetic and Electric Fields.—The magnetic and electric fields will form the most important part of our subject. It is through these fields, and almost through them alone, that we get to know about what we call magnetism and electricity. It was not till their existence and their effects were properly recognised that modern progress became possible. They mark the boundary between the ancient and the recent electrical ideas. A dynamo and a motor depend on magnetic fields; the speed at which a motor runs is changed by altering its magnetic flux. Wireless telegraphy could not exist without the two fields, both magnetic and electric. The transmitting apparatus is merely a device for creating these fields on a large scale, and as the flux extends farther and farther it at last reaches the receiving apparatus and gives rise to the signals.

* This is only another way of saying that the two unlike charges neutralise each other's distant effects.

The last sentence is worth the special attention of the reader, for the distant action is not attributed in words to the transmitting apparatus, but rather to the "fields" which are travelling through space. And it is noteworthy because it is a better way of regarding even simple magnetic and electric experiments. The experimental foundation already laid down will not suffice until it is looked at from this new standpoint. As long as the invisible fields are ignored, it is impossible to reveal the secret actions of the mysterious agents, magnetism and electricity. To get an idea of what such neglect may mean, let the reader imagine men coming within the range of a tree which emitted and was surrounded by a deadly vapour, and other persons then trying to explain why the former fell down dead. Ignoring the vapour, all kinds of inadequate theories would be propounded. It would be thought that the tree struck the men in some mysterious way, or that it killed by its mere presence. As soon, however, as the existence and nature of the vapour were recognised, the cause of death would be made much clearer. In a similar way a charged body or a magnet acts through space, and this it was formerly said to do by influence, but we now know that its effects are really the effects of its field—of the intangible flux by which it is surrounded and which is roughly shown in Figs. 9 to 15*a*. The only caution here needed is that neither the magnetic nor the electric flux is exactly like a vapour. That idea is introduced to make the point clear; fuller explanation will be given presently.

We may illustrate the utility of these fields by reconsidering the act of magnetisation in the light of them. When a piece of iron or steel is magnetised this is really accomplished by putting them in the "field"

of another magnet. The language ordinarily used is quite misleading: the reader is told to rub the steel with one pole of a magnet, and the instruction is understood because rubbing is a well-known operation. In reality the rubbing is only a way of thrusting the most intense part of the "field" of the magnet into the new piece of steel. In these days, when magnets have often to be made as strong as possible, they are not rubbed at all: a specially strong "field" is set up and the steel placed in it. The steel is at once fully magnetised.

As we have already said, the working of a dynamo depends on the creation of an intense magnetic field. Even a motor could not draw a tram-car or train but for a large magnetic flux concentrated in a small field, while the telephone could not transmit human speech, etc., if it were robbed of its field, or if the sound vibrations were not used to cause fluctuations in that field.

These observations will lead the reader to give close attention to what has been said about the electric and magnetic fields in the last two sections. They form the key to the whole subject.

Experimental Foundations — Electricity in Motion. — Electric currents have been known and studied for a hundred years, though in the form of lightning flashes they have been seen from the first dawn of human intelligence. It was the invention of electric batteries which enabled men to study electric currents at leisure, and thus discover the general effects they produce. When these batteries were able to provide strong currents it was soon found that they had a tendency to warm the bodies through which they passed, and our present electric lamps of both kinds (arc lamps and glow lamps) are the consequence. It

was also found that when passed through certain fluids, like vinegar or solutions of metals, an electric current produced certain changes of a chemical nature, and this led to electroplating, etc. Again, it was discovered that there was some peculiar connection between an electric current and magnetism. To find a link between electricity and magnetism had been the object of many researches, though all failed until, in

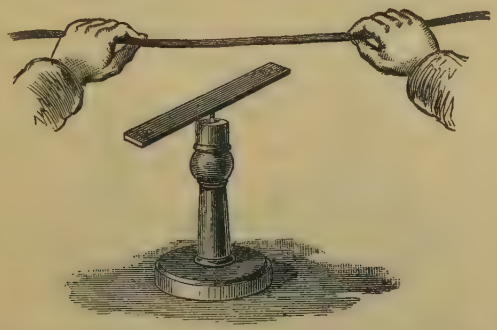


Fig. 16.—An electric current deflecting a magnet from the N. and S. line.

1819, the Danish philosopher Oersted showed that the connecting link depended on the electricity being in motion; that an electric current behaved to some extent like a magnet. This implies the existence of a magnetic field round an electric current. The experiment made by Oersted consisted in passing a current over or under a compass needle, as shown in Fig. 16. The needle is at once twisted on its pivot, and moves through an angle depending on the strength of the current. When the current ceases the magnet turns back again to the north and south line.

This is a simple experiment, and there does not

seem anything remarkable about it now, but in 1819 it created a great sensation. The discovery was rightly regarded as having the most profound significance, and it has served as the basis of many instruments, telegraphic and other. It has, moreover, a wide theoretical bearing, as we shall see.

The next great discovery was made by Faraday in 1831. Oersted's experiment had made it clear that

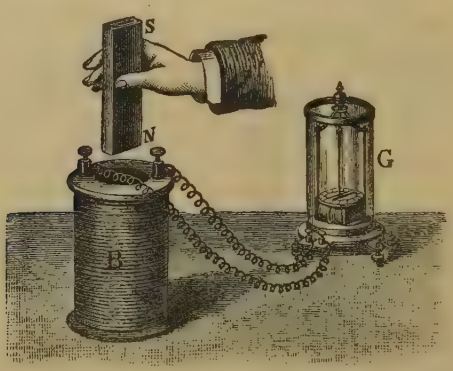


Fig. 17.—Producing an electric current by putting a magnet inside a coil of wire.

an electric current could produce a magnetic effect, that the *motion* of electricity was a connecting link between electricity and magnetism. Faraday looked for this connecting link in the converse way. Why should not the *motion* of a magnet produce an electric effect? After many failures he found that his expectation was justified. By moving a magnet he could set electricity in motion, getting electric currents. Fig. 17 shows one form of the experiment. When the magnet N S is moved near the coil of wire B, an electric current is set up, and can be detected by the galvanometer G.

Still later came the discovery of a motor. A moving magnet had made electricity flow in a conductor. It was found that if a current and a magnet were brought near together, they at once began to push each other in certain directions, and that these mechanical forces could be used to produce rotation.

Notwithstanding these enormous advances, the meaning of electricity and of electric currents remained very obscure till experiments on vacuum tubes began to be systematically pursued, and these have now led to very definite ideas and theories.

Electric Discharges in Vacuum Tubes.—Let a long glass tube (Fig. 18) have metallic electrodes P_1 P_2 sealed through the glass, and let these be connected to the high-pressure terminals of a spark coil (Fig. 19, also Fig. 139, p. 231). A spark passes between P_1 and P_2, its outline being that of a crooked line of white light, looking slightly brighter at the positive end.

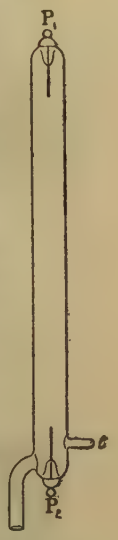


Fig. 18.—Tube for observing spark at various exhaustions.

Now let the air be gradually exhausted from the tube by means of a pump connected with the side tube *t*. As the exhaustion proceeds the spark changes its appearance in a most remarkable manner.

1. Its colour changes to a beautiful purple, and its outline becomes less definite; it looks like a fluffy purple cylinder of light in the inside of the glass tube. At the higher exhaustion this purple light fills the tube, and then gives place to a greenish-yellow phosphorescence on the glass itself. With the very highest vacuum (about one-hundred-millionth of the original air left) it

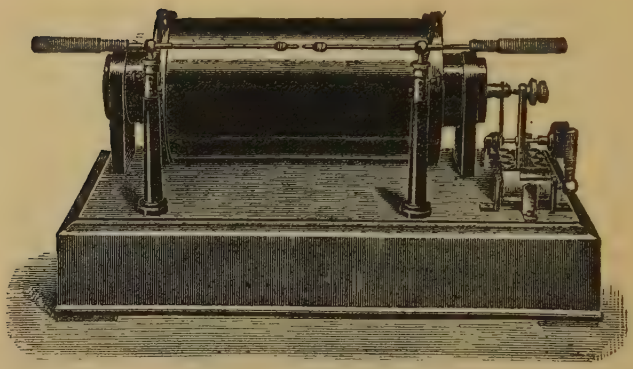


Fig. 19.—Induction coil for producing sparks. (*Newton & Co.*)

becomes very difficult to get a spark through even a short length. At less exhaustion sparking is much easier than with air at ordinary pressure.

2. At a high exhaustion the discharge from the

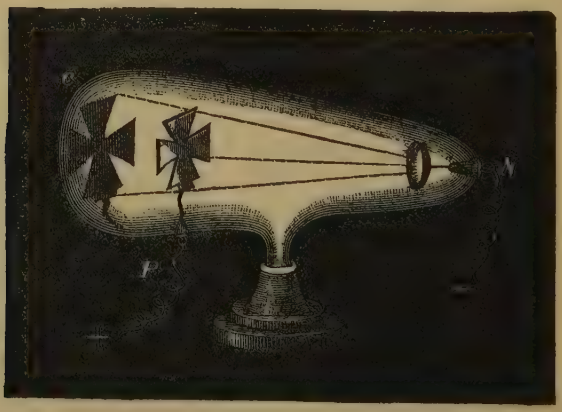


Fig. 20.—Shadow of the cross (cathode rays pass in straight lines).

negative electrode proceeds in straight lines instead of passing to the positive pole. Fig. 20 illustrates this. The rays from the cathode strike an aluminium cross and cast a shadow of it on the glass behind. The definite outline of this shadow proves that the rays from the negative (cathode rays, as they are called) must pursue perfectly straight paths.

3. The cathode rays have great energy. In Fig. 21 the cathode or negative electrode is shaped like a shallow cup; the anode or positive electrode is a small piece of platinum foil. The cathode rays assume a conical form, and are focused on the platinum, which is speedily made red-hot by their impact. Obviously the cathode rays are moving at a great speed, and the energy of motion is converted into heat as they strike the platinum.

Fig. 21.—Concentrated cathode rays producing heat. (*Griffin & Co.*)

4. In Fig. 22 a little windmill is arranged with its axle resting on two glass supports. When the spark is allowed to pass, the mill turns round on its axle, showing that the cathode rays are able to impart motion: obviously they give a clear mechanical impact.

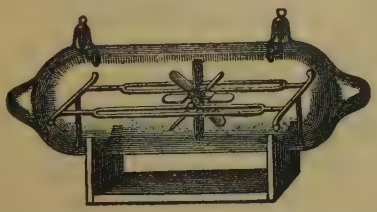


Fig. 22.—Windmill moved by cathode rays. (*Griffin & Co.*)

5. The cathode rays are deflected by a magnet. In Fig. 23 a magnet is fixed near the cathode stream, which is deflected. In this case the stream is forced downwards. If the magnet poles change position, the cathode stream is forced upwards.

It is noteworthy that the reversal of the poles is better described as *a reversal of the direction of the magnetic field.* In both cases the cathode stream passes *through* the field of the magnet and experiences a force. When the field is reversed in direction, the direction of the force is also reversed.

These experiments with the magnet prove that the

Fig. 23.—Cathode rays deflected by a magnet. (*Griffin & Co.*)

cathode rays consist of electrified particles; they cannot be mere particles of air. Air particles, whether at rest or in motion, are not deflected by a magnet. The rays behave like a current of electricity in a wire, for that is likewise moved aside by a magnetic field.

Cathode Rays.—It is evident that in these experiments we are dealing with peculiar electric conditions. It was at first thought that the cathode rays consisted of particles of air which carried an electrical charge: that each particle became negatively electrified by contact with the cathode, and was then repelled with great velocity along the vacuum tube. Sir William Crookes, who was the first to perform

many of these experiments, thought that the air was reduced in these high vacua to a special state, much finer and subtler than that of a gas. But this idea has given way to another in consequence of the researches of Professor J. J. Thomson, of Cambridge. The following summary will give some idea of his methods and results :—

(*a*) By carefully measuring the curved path of cathode rays acted on by a magnetic field, and combining this with a similar effect produced by an electrical field, Professor Thomson has measured the velocity of the cathode rays, and found it to be as high as 100,000 miles per second.

A velocity so high as this is incredible from the ordinary standpoint. The forces required to make atoms of air move at this speed must be far greater than any which the electric conditions can set up. Even if the tube contained atoms of hydrogen—the lightest of all known atoms—they could not be made to move with a velocity like that mentioned.

(*b*) Professor Thomson showed that these flying particles were the same in tubes which had been filled with different gases. This made it probable that the cathode rays differed from any ordinary matter, and suggested that they were somehow obtainable from all kinds of matter under suitable conditions.

(*c*) Professor Thomson then devised methods for measuring the number of these flying particles in a given vessel; for finding the quantity of electricity in each particle; and for determining the mass of each of them.

The net result was to prove that the mass of each particle was nearly 1,000 times less than the smallest

atom. There was, in fact, no evading the conclusion that the cathode rays consisted of particles or corpuscles of electricity. In this highly-exhausted tube we at last meet with the electricity free from association with matter, and have arrived at the goal of our researches.

Consider what the experiments have revealed :—

(1) Electricity is found in every known substance. (2) There are two kinds of it, each of which is able to neutralise the other's effects. (3) The negative part consists of minute corpuscles, much smaller than the lightest atom. (4) The positive part also consists of minute parts, though not so small as the negative corpuscles.* (5) The negative and positive corpuscles can be detached, forming electric charges, which exercise strong attractive and repellent forces. (6) When the corpuscles move they constitute an electric current and always set up a magnetic field in the space round about them.

The corpuscles of electricity are called *electrons*, and we shall speak of negative and positive electrons when the occasion calls for it.

Theoretical Foundations.—Having found that electricity is composed of minute corpuscles called electrons (of which there are two kinds), we have next to ask : What are the electrons made of?

To this question science replies : Electrons are made out of the ether. A scientific man regards the universe as made up of two distinct objects of study. One is the material world, the other is the universal medium "ether." To ascertain what science thinks about electricity we must learn what it says about matter and ether.

* Some authorities think that the positive corpuscle has never been found free from matter, but we shall assume that it can exist alone.

Matter.—The material world is formed of the combinations of about eighty different elementary bodies. Most of these are very rare, and need not concern us. We are well acquainted with the metallic bodies, like silver, gold, etc. All metals are elements. Most readers also know such elementary bodies as carbon (charcoal), sulphur, phosphorus, oxygen, hydrogen, etc. Each element is composed of small parts called atoms, which were supposed till recently to be quite unchangeable. The relative weights of the atoms of different elements are established. The lightest atom is that of hydrogen; that of copper is 63 times heavier. Two hundred million atoms of copper side by side would cover 1 inch; ten quadrillions of them (10,000,000,000,000,000,000,000,000) make 1 pound.

Properties of Matter.—All material bodies gravitate—that is, they attract each other. This attraction is independent of the *kind* of matter and of its state. Sulphur and hydrogen attract equally with iron and carbon, etc. The force of attraction depends on the quantity of matter and on the distance apart, and on these conditions only.

Matter also possesses inertia. If at rest, it remains at rest. If in motion, it continues in motion. In either condition, however, forces may act on it so as to change its state, whether of rest or motion.

The Universal Ether.—Besides the material world science says there is an ether. This is a subtle, peculiar medium *filling all space*. It differs from matter in many ways. First, it is not made of atoms. It is not found in parts, either large or small. There are no "lumps" of ether. It has in reality a structure similar to that of an infinite sea of water or jelly: without bounds or limits of any kind. It cannot be cut or parted, neither can holes be made in it. It

stretches from atom to atom, likewise from the earth to the remotest star.

The ether is, in all ordinary senses of the word, invisible and intangible. We exist in it, as the fishes exist in water, without knowing it. It serves to transmit the vibrations of heat and light from the sun to earth and from one part of the universe to another. Hence it is called the luminiferous ether. It also serves to carry the waves used in wireless telegraphy, so that we may just as rightly call it the electric ether. It is the medium which is revealed to us (in a distorted condition) in the electric and magnetic fields; hence we may very properly call it the electromagnetic ether.

The properties of the ether are so wonderful that it transmits a disturbance (say a ray of light) at the enormous speed of 186,000 miles per second.

Electricity.— We are now in a position to understand the scientific meaning of electricity. It is made out of ether by an alteration of the usual properties. It is a minute portion of the ether which has been altered in one of several possible ways. Scientific men describe these ways as strains, but their meaning will be more intelligible if explained in the form of illustrations. These we shall attempt. Suppose we could take two small portions of the ether and give them a rotational movement, making one rotate clockwise and the other anti-clockwise. We should then have two minute portions of the ether which would differ from the rest of it, and they would in many ways behave as positive and negative electrons. A similar result would follow if we could condense one minute particle of the ether and rarefy another. These particles would act as positive and negative electrons. We can get a very good model of the electrons by falling back once more on water as a symbol for the ether. For we can take two

particles of this water, and freeze one into ice and heat the other into steam. They are still made of water-stuff, but one is a cold and the other a hot particle of it.

If the ocean of water had many of these hot and cold particles it would so far resemble the ether with many of its parts changed into positive and other parts into negative electrons. The ice and steam particles would have many properties akin to those of electrons. While they were mixed they would neutralise each other: we could not feel the cold ice or the warm steam. To find out the properties of either we must find a way of *separating* the ice particles from the steam particles. A great difference would arise if we gathered a number of ice corpuscles together in one place.

Although each atom of ice might be very minute and of little importance, some quadrillions of them might form a very tangible and disturbing block. In like manner an equally large number of steam corpuscles might be a source of disturbance. And yet these two sets of corpuscles would, on being mixed, apparently disappear.

In using this illustration we have supposed that, while the ice and steam can mix, they cannot act on each other: the steam cannot melt the ice, nor can the ice condense the steam. They are used here as a rough model of the way in which the ether may be modified so as to form two different kinds of electricity. They serve to show what is meant by the statement that negative and positive electrons consist of minute portions of ether which have been oppositely strained in some way.

The question is so interesting in itself and so important for making many things clear that another

analogy will be offered. In some respects it is not so exact as those already given, but it is more comprehensible by those who are not habituated to scientific work.

Let us imagine that our atmosphere is more or less like the universal ether, and let us assume that there is an immense number of small parts of the atmosphere which have been compressed and an equal number of parts which have been rarefied or expanded, and that these compressed and rarefied portions can mix together without destroying each other. Obviously, when they are so mixed the general effect will be one of neutrality—neither compression nor rarefaction. But if by any means a number of the compressed portions could be separated from their rarefied fellows, we should obtain two portions of air possessing very different properties; indeed, they would behave like "opposite airs" in many ways. Now we may take this as a rough analogy for electrons and the ether. The compressed corpuscle of ether may be taken to be the negative electron; the rarefied or expanded corpuscle may be taken to represent the positive electron. The idea is not actually true: it is doubtful if the ether can be compressed or rarefied. But it certainly can be strained, and strained in opposite ways, and it is convenient to speak as if the two opposite strains were those of compression and rarefaction. We shall therefore adopt this analogy in what follows.

The value of the idea can be shown at once. The idea of a "field," like the electric field described on page 12, is a natural outcome of compression or rarefaction. Imagine a great block of jelly or of glass, and suppose that in its centre is a small portion which has been compressed. Such a corpuscle must exert extra pressure on the parts immediately surrounding

it, and these in turn on those which lie beyond them. A compression stress will be felt throughout the block, and this stress will be like the "electric field" accompanying an electron or an electric charge. Radial lines will represent the direction in which such a stress acts and will be exactly like those of Fig. 14.

If another compressed corpuscle be formed in the glass or jelly it also will have its stress and its field. Both the corpuscles will increase the stress in the space between them, and this will be a region of maximum stress. Hence the two corpuscles will repel (Fig. 15*a*).

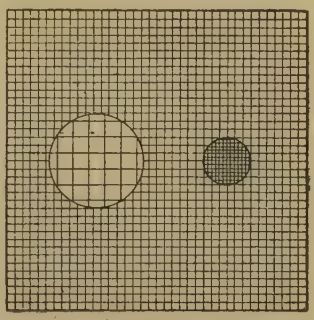


Fig. 24.—Diagram of a compressed and a rarefied medium.

If we imagine a corpuscle of the glass or jelly rarefied instead of compressed, the preceding statements will still be true, but the stress will be of an opposite character; the lines will have similar shape, but have a contrary direction; a compressed corpuscle will be attracted instead of repelled. Using these ideas as a convenient analogy, a crude attempt to *suggest* the electrons is made in Fig. 24. The shaded part represents the ether; the darker circle is a negative electron (20 billions to the inch); the lighter circle is a positive electron. Each of these is made of the ether strained in some way. Particles like these in glass would certainly strain the surrounding parts, and the ether is supposed to suffer similar pressure.

Helped by these analogies, we now take it for granted that there is a medium called the ether filling

all space, and that certain small parts of it are strained —say some as a compression, others as a rarefaction— and that these small corpuscles of strained ether are to be called negative and positive electrons.

Sizes of Electrons.—An electron is very small—so small that what we call an atom of matter is large compared with it. If *atoms* were placed side by side in a line it would require about 200,000,000 of them to cover one inch; but the number of *electrons* required to cover an inch is practically 20,000,000,000,000 —that is to say, about 100,000 electrons can be placed in a line and yet lie within the diameter of one atom. Particles as small as this may easily find their way among the atoms of even dense metals. The figures given are so unusual that the reader cannot easily form ideas about them. Let him, therefore, take an ordinary pin, and note the following facts. The metal of which it is composed is built up of atoms. There are about 10,000,000 of these atoms in the thickness of the pin, and each atom contains about 45,000 electrons. This last figure is that given by Sir Oliver Lodge for copper, and is based on the experiments of Professor J. J. Thomson.

Taking stock of the position to which we have now been led, we have to look on the whole material world as built up of different elementary atoms of matter, and that all these atoms contain numbers of corpuscles of electricity known as electrons.

CHAPTER II

PRACTICAL APPLICATIONS—DYNAMOS

HAVING explained what is meant by electricity, we propose to give some account of various applications of scientific knowledge to practical work. The electrons of which we have spoken exist in every material body. They are found in the atoms of every element, but as they are usually mixed in equal quantities their presence is not discerned till friction or something else disturbs the even distribution.

Modern electrical developments are due to the discovery that a dynamo can separate positive and negative electrons; for it has been found that these separated electrons are able to re-unite. They will flow together if they are joined by a conductor like copper; or by means of a discharge through the air, as in an arc lamp; or in many other ways at which we shall glance. A word or two on conductors and insulators will be helpful.

Conductors and Insulators.—In some substances electricity flows with comparative ease. It seems to meet with very little friction or resistance. Such substances are called conductors. The metals are the best conductors, though they differ largely in the amount of resistance they offer. Copper is the best conductor; iron has only one-sixth its conductivity. The size of the conductor also exerts an influence. If six iron wires be laid *side by side* their joint conductivity is equal to that of one similar wire of copper. Finally, the conductivity is reduced (that is,

the resistance is increased) according to the length of the conductor.

Other substances—like glass or india-rubber—do not act in the same way. The electrons cannot flow continuously through them. If an electric pressure acts on them it appears to displace the electrons a little way only, so that they spring back again if the pressure be removed.

In practical affairs, copper wires are arranged as conductors to carry the current from and to the dynamo, and these conductors are surrounded by india-rubber or other insulator to prevent the electrons from leaking by some unintended and useless path. The arrangement, therefore, corresponds to the system of water-pipes by which we are usually supplied with water. The copper is the part through which electrons flow, and therefore corresponds to the *hole* in the water-pipe. The india-rubber or cotton insulator prevents leakage, and therefore corresponds to the iron or lead walls of the water-pipe. It is clear that when pressures are high the insulating wall must be made thicker and stronger.

Conducting Circuit—Indestructibility of Electrons. — In practice of the ordinary kind it is absolutely necessary not only to provide conductors; they must be arranged in a *circuit*. The conducting path must have no beginning or end.

The reason of this is very curious. If the terminals of a battery or dynamo be joined to wires which are not connected (so that there is no circuit) the machine separates a certain number of electrons, thrusting positive on to one wire and negative on to the other. But it cannot go on doing this. As the electrons accumulate on each wire they set up a violent self-repulsion, and this becomes so great that the dynamo

(or battery) can separate no more. But when the two wires are joined, so as to form a circuit, the separated positive and negative electrons can flow together again, and the whole action can be made continuous. As a matter of fact, a circuit is necessary for anything to flow continuously. The blood could not flow constantly in our arteries and veins unless by a circuit: a continuous flow *means circulation.* As much blood must enter the heart as leaves it. In the same way electrons circulate. As many enter a dynamo as leave it. They are never destroyed.

This last sentence will probably astonish the reader. He will think of the work these electrons do in a lamp or a motor, and he will say surely they are consumed. But it is not so, any more than the blood is consumed as it passes through the body. They are changed, but the change is not a loss of electrons; it is a loss of pressure. We shall understand this better after explaining how a dynamo is made.

How a Dynamo is Made.—The earliest and simplest dynamo machine was one which was designed by Faraday. It was in the year 1831 that he made the ever-memorable experiments which led to the design of the present dynamos. He discovered that when a magnet is moved near a conducting body an electric current is set up in the latter. It was not necessary for the magnet to touch the conducting body; the current seemed to depend on the mere presence of the moving magnet. But Faraday, with great penetration, traced the effect to the *magnetic field.* He showed that, although the magnet might not touch the conductor, its invisible flux of "lines" penetrated into the conductor, and he pointed out that it was this moving magnetic flux which set up the electric current. As the magnetic flux moves

among the electrons it pushes the two kinds apart. The effects obtained by Faraday were very minute; so minute, indeed, that they would have been disregarded by ordinary people, but he saw clearly that their magnitude could be increased whenever he or others liked to pursue the matter. The gigantic machines of modern days are developments of the principle which was then revealed. Let us look first at his simple machine, and then compare it with a more recent design.

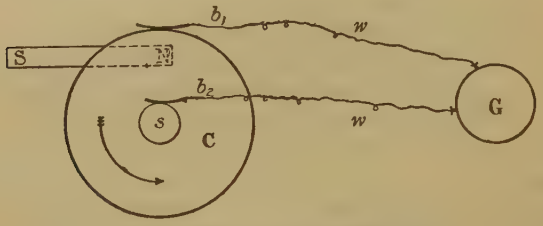


Fig. 25.—Faraday's disc dynamo.

Faraday's Disc Dynamo.—In Fig. 25, C is a metal disc which can be rotated by means of a spindle *s*. The driving mechanism is omitted. Two strips of brass, b_1 b_2, press on the disc, one at its edge, the other near its centre (close to the spindle) or on the spindle itself. The strips are joined by a wire *w* to a current detector or galvanometer G. When the disc is rotated no current flows in the wire *until the pole of a magnet* N S *is placed near the disc*. As soon as this is done a current begins to flow, and continues as long as the magnet is there and the rotation of the disc is maintained. Two conditions are necessary: first, a magnetic flux penetrating the conductor; secondly, motion of the conductor.

Further experiment shows that the conductor may be kept still, provided the magnet is moved.

The current obtained from such a disc is feeble, too weak, in fact, to do anything more than move the needle of a delicate galvanometer. But the method of increasing the effect is already half revealed. We must have stronger magnets and a number of conductors before any powerful effects can be seen. It

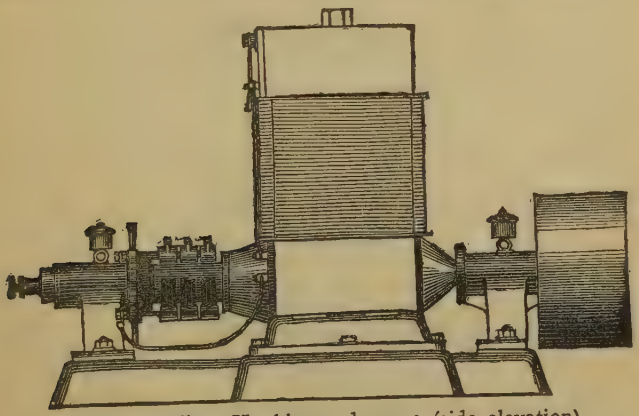


Fig. 26.—Edison-Hopkinson dynamo (side elevation). (*The Electrician.*)

is in these directions that development has taken place, as will be seen in the modern type.

How a Modern Dynamo is Made.—In a modern dynamo intended to give continuous currents there are three chief and necessary parts. First, the magnetic part; secondly, the armature conductors; thirdly, the commutator and brushes. We shall take these in order. Fig. 26 gives a general view of the whole machine. Its action will be gathered from the following paragraphs.

Magnetic Part.—This consists of good soft iron,

arranged as in Fig. 27: M M are the limbs of the magnet, Y is the yoke, P P are the pole pieces, A C is the armature core.

The whole system is magnetised by means of coils of copper wire, C C, wound on the limbs. These coils are known as exciting coils or "field" coils, and are seen only in section. The iron used for this magnetic part of the dynamo is very soft, and is capable of

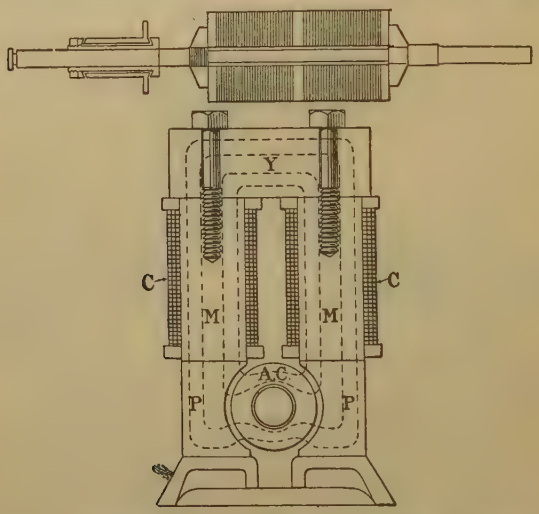


Fig. 27.—Magnetic part of Edison-Hopkinson dynamo.

being magnetised to a much higher intensity than a corresponding body of steel. It is unlike steel also in another respect, namely, that it loses its magnetism almost as easily as it gets it. Hence it is magnetised only while it is under the action of some "excitation" or magnetic force. In the case of a dynamo, this "excitation" is provided by a current flowing through the coils on the magnet limbs, as already mentioned.

The same coils are called "field" coils because in exciting the magnets they establish a "magnetic field" in the air gaps between the pole pieces and the armature core (Fig. 27). The peculiar magnetic flux of which this field is made up exists not only in the air gaps: it is established throughout the iron circuit, as shown by the dotted lines. The pole pieces are needed to make the air gaps of uniform value. They also facilitate the establishment of the magnetic flux through the armature.

Indeed, the whole of this part of a dynamo is designed to get as many lines of magnetic force through the armature as possible. The armature core is made of the very best magnetic iron for the same reason. Perhaps it is desirable to say that the iron of the armature core differs from the other parts in not being made of a solid piece. It is built up (as seen at the top of the figure) of thin washers, which are separated from each other by very thin paper or a layer of varnish. This is to prevent currents forming in the iron.

If we compare this magnetic system with that used by Faraday we find an enormous increase. In his machine (Fig. 25) the number of magnetic lines might be several thousands, though probably less.* In a modern machine the number will probably be many millions of lines. In the machine whose magnetic part is given in Fig. 27 the number of lines which crossed the armature was between ten and eleven millions.

Armature.—The armature of the Edison-Hopkinson machine consisted of the laminated iron core seen

* In Faraday's day the number of magnetic lines used in any experiment was not measured. It is possible that his disc moved through no more than 3,000 lines.

at the top of Fig. 27, with about 160 conductors arranged on its face. These were wound on the principle

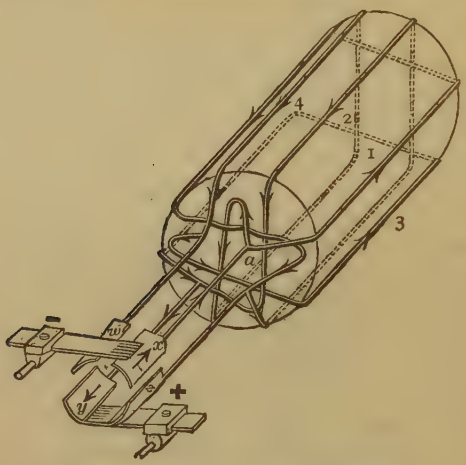


Fig. 28.—Four-coil drum winding.

known as the "drum" winding, as contrasted with that known as the Gramme "ring" winding. A

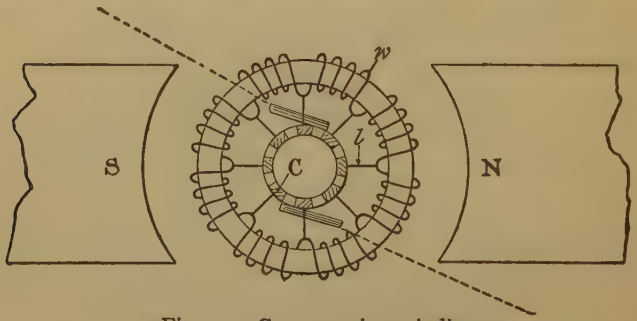


Fig. 29.—Gramme ring winding.

general idea of the drum method is shown in Fig. 28; the Gramme ring is indicated in Fig. 29.

The ring winding is easier to follow. The conducting wire *w* (duly insulated, of course) is wound continuously round the iron ring. There are 32 turns shown in the figure, divided into 8 coils of 4 turns each. At the junction of one coil with the next one, short wires or lugs *l* are soldered to the winding and run to the commutator segments, one of which is lettered c. Of these we shall speak in the next section.

In Fig. 28 the drum method is indicated by a series of four coils (1, 2, 3, 4) wound round the core. The difference lies in this: none of the wires is taken through the *inside* of the ring. A wire proceeds from the front end to the back, then bends across a diameter to the opposite face, returns to the front, and so on. The whole is divided into coils by lugs running from points like *a* to *w*, *x*, *y*, *z* respectively.

Fig. 30.—Armature core with slotted surface.

In the case of both ring and drum, the smooth iron core is covered by the windings and cannot be seen. The number of wires put on is determined by the pressure required; the size of the wire depends on the current which the machine must deliver.

A few years ago nearly all the armatures were smooth-core armatures (as shown in these diagrams, Figs. 28 and 29). But the increase of power required for public purposes has made it necessary to place the armature conductors in slots. The iron core plates are no longer smooth and continuous at the circumference, but slotted in the manner shown in Fig. 30. This change allows the conductors to be wound in the slots, where they are protected from mechanical

injury. It also allows the armature core-iron to be of larger diameter. When the wire is wound on a core with a smooth surface, it is necessary to allow a sufficient distance for the copper wire between the armature iron and the pole pieces, and this means that about half an inch of air intervenes between the two irons. Now that the wire is placed in slots, the thickness of the air gap can be diminished very much, with a consequent increase in the intensity of the magnetic flux, for it is much easier to establish lines of magnetic force in iron than in air.

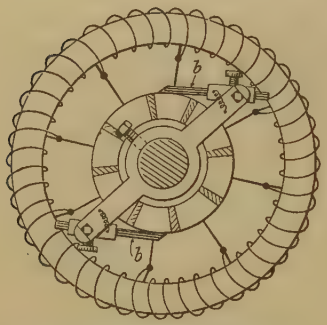


Fig. 31.—Brushes in holder, pressing on rotating commutator.

Commutator and Brushes.—This consists of a number of segments of copper several inches in length and of a wedge shape. They are separated by a thin strip of mica, which serves to insulate them from each other. They are also insulated from the shaft and other parts of the dynamo. As already stated, each copper segment is connected to the armature conductors by a short wire lug. These points are brought out in Fig. 29 by a slight exaggeration. The object of the commutator and brushes is partly to allow the armature to rotate and yet permit contact to be made between the conductors wound on it and those outside.

To see how this is done we must turn to the brushes, *b b*, Fig. 31.

These are either strips of copper gauze or blocks of carbon, held *fixed* in an insulated holder. They

are acted on by a spring, so as to press on the commutator. It follows that when the armature rotates, and the commutator rotates with it, the brushes make a rubbing contact with the commutator segments. As each segment is joined by a wire lug with the armature winding, it is easy to see that each brush will be put successively in contact with different parts of

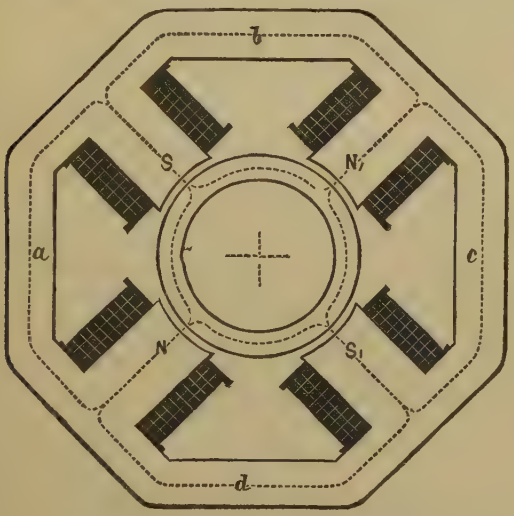


Fig. 32.—Four-pole magnet for dynamo.

the armature winding, and the current can be taken off by one brush and returned by the other. The commutator also serves another purpose, but the explanation of that must be left to a later section.

Other Forms of Dynamos.—Other dynamos differ from the one shown, in having a different magnetic system, or a different winding for the armature. Instead of a magnet with two poles, as in Fig. 26,

we may have one with four or more, as in Fig. 32. In every case the number of north and south poles must be equal. In Fig. 32 the way in which the magnetic lines (*a, b, c, d*) are disposed is shown. The advantage of four poles over two lies in the fact that larger armatures and commutators and lower speeds can be used. The armature conductors pass through a given number of magnetic lines twice as often in each revolution, and the electric effect rises in proportion.

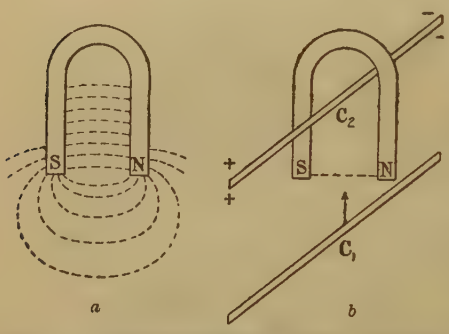


Fig. 33.—Copper conductor moving through magnetic flux.

a, flux lines; *b*, moving copper wire.

These variations will suffice to give the reader an idea of the many ways in which magnets can be manufactured, as far as the form of the iron is concerned. We shall deal with the exciting coils later.

How Dynamos do their Work.—The reader will now be prepared for the following statement: A dynamo is a machine wound with copper wire, which wire contains a vast multitude of mixed electrons, and it is the office of the machine to exercise pressure on these electrons, urging the positive ones to one terminal and the negative ones to another.

Fundamental Dynamo Experiment.—*The invisible flux between the poles of a magnet is the agent by which a dynamo puts pressure on electrons.* Fig. 33*a* shows the shape of the flux in the case of a

simple horseshoe magnet, and the lines drawn represent a definite amount of flux. If the strength of the magnet were doubled the flux would be doubled in amount, but its shape would be unaltered. There would be twice as much flux throughout the same space; its intensity would be doubled.

Now consider Fig. 33*b*, where the same magnet appears along with a copper wire c. This wire is to be moved from the lower to the higher position (c_1 to c_2), and we notice that this cannot be done without cutting through the flux represented in Fig. 33*a*. It follows that not only the wire but also the electrons in the wire cut through the flux. When they do so they are acted on by it. The positive electrons are urged one way, the negative electrons in the reverse way, with the result that the ends of c become electrically charged during the time of cutting the flux. This is shown by the + and − signs, placed in the figure at the ends of c_2. If now the wire be dragged down from c_2 to c_1, the electrons in it *cut through the magnetic flux in a reverse sense,* and they are urged in a reverse way. The ends will then be oppositely charged, the right end becoming positive and the left negative.

Simple Dynamo—One Wire in Armature.—The simple experiment of moving the wire up and down across the lines of force, as in Fig. 33, would serve as a dynamo, though a feeble one. We could fasten the wire to a rod moved up and down by an engine, and attach a wire *w w* between its ends (Fig. 34). This would make a conducting circuit.

As the wire moved upwards, a current would flow as shown by the arrows. This is, of course, the direction in which positive electrons move; negative electrons move the reverse way. When the motion

is reversed the pressure and current will also reverse, so that as the wire moves up and down the current is an alternating or reversing one.

Such a dynamo would be of no use, because it could only give very low pressures—too low for practical work. To obtain higher pressures we must get higher speeds for the wire, and many wires must be arranged so that the pressure in one is added to that in the other. These objects are accomplished by substituting rotation for the to-and-fro movement, and by using many wires. We will explain carefully how two wires may be used.

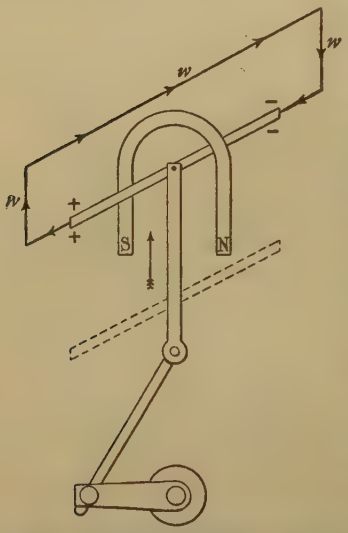


Fig. 34.—Simple dynamo, single wire.

Simple Dynamo — Two Wires Rotating in Magnetic Field.—Fig. 35 shows a magnetic field between two poles, N and S. Attached to a central spindle *s* and rotating with it are two wires w_1 w_2. The spindle and wires are shown in section only; w_1 lies near the bottom of the field, w_2 near the top. If the spindle be turned in a clockwise sense, as shown by the arrows, w_1 will move upwards through the magnetic lines, while w_2 will move downwards through the same flux. There will therefore be an equal pressure on the electrons in w_1 and w_2, but it will act in contrary senses. The near end of w_1

becomes positive, the near end of w_2 negative. This is suggested by Fig. 36*a*, where a longitudinal view of the wires is given.

Now suppose that the two conductors are joined at the far end, as seen in Fig. 36*b*. The pressure in one adds to that in the other; there will be no free electrons at the far end of either; the two actions conspire to urge positive electrons to the front of w_1 and negative to the front of w_2. These get double charges (Fig. 36*b*) and the electric pressure between the ends is doubled.

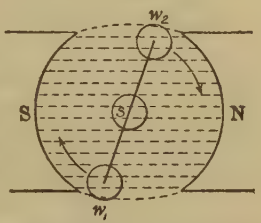


Fig. 35.—Two wires rotating in magnetic field.

By pursuing this method and using many wires the pressure of one can be added to that of others, and so armatures can be made whose pressure is very great.

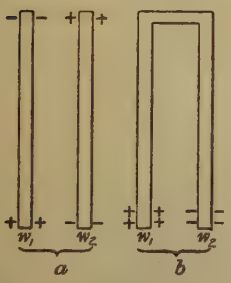


Fig. 36.—Electrons separated: (*a*) in each wire; (*b*) in wires when joined.

Brushes.—By a proper arrangement of wires rotating in a magnetic field we can obtain what pressure we like up to a certain maximum. But two results have to be kept in mind. First of all, it is a reversing pressure, because each wire, as it rotates, moves alternately up and down through the magnetic lines. Secondly, it is necessary to arrange some contact with the ends of the wire as it rotates, otherwise the pressure will not serve any useful purpose. That a rubbing contact is necessary is clear; if we fasten two wires to the ends of the

armature winding, they will be twisted together as the armature rotates, and they must speedily be broken.

The rubbing contact is made by means of brushes. The simplest way is shown in Fig. 37, in which s is the armature shaft; w_1 w_2 are the ends of a simple coil, say, of two wires, each end being connected to brass rings fixed to insulating discs i_1 i_2. The end w_1 is joined to r_1; w_2 is joined to r_2, this last end having to pass through the insulating disc i_1 to reach its ring.

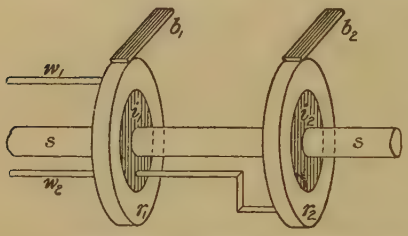


Fig. 37.—Simplest method of connecting armature to external circuit.

Resting on the rings are two fixed brushes, b_1 b_2. It is evident that, as the armature rotates and the rings rotate with it, the brushes maintain contact with the rings and therefore with the ends of the wires. Thus b_1 is always in touch with w_1, b_2 with w_2. In this way an alternating current flows in any conductor connecting b_1 and b_2.

We shall now explain how this alternating current is transformed into a continuous one in the external part of the circuit. The reader will be assisted if he bear in mind the fact previously established—that the reversal comes in each wire as it passes from one pole to the next. In the diagrams we are now using the reversal comes as each wire reaches the top and bottom positions.

How a Commutator Acts.—It is now easy to show what the commutator is, and how it does its work.

Take the simple armature, as already described: two wires joined together at the far end and connected to two insulated rings at the near end (Fig. 37). We find that the current is reversed every time the wires get to the top and bottom of the field, and it is our wish to commute these alternations, so that they flow in a given single direction externally.

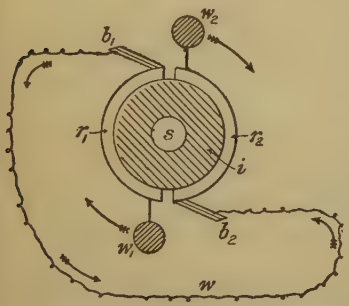


Fig. 38.—Two-part (or split-ring) commutator.

Evidently we could get this *if it were possible to change over the connections of brushes and rings just when the armature wires came to the reversing position.* If the brushes could be reversed at this moment the current would be compelled always to flow in the same direction in the external conductors. This great improvement can be done in the simplest manner. All that is needed is to join the armature wires to two *half rings, on which the brushes press alternately.* It is thus easy to make each brush reverse its connection to the armature wires just when the current in the armature reverses. Fig. 38 will show how this is done: s is the armature spindle, i is an insulating disc on which are fixed two half rings of brass, r_1 r_2. The ends of the two wires on the armature are shown shaded, and marked as before, w_1 w_2. They are joined to r_1 r_2 respectively. All these turn with the shaft s. The fixed brushes b_1 b_2 press on the half rings at top and bottom, and therefore are in touch with w_1 and w_2 respectively. It is easy to see that, as the shaft and

rings rotate, the brush b_1 will remain in contact with w_1 as long as the latter is moving upwards, b_2 remaining in contact with w_2 as long as it is moving downwards. During this half revolution w_1 is positive, and the brush b_1 is therefore positive. The current will flow externally from b_1 to b_2, as shown by the arrows. At this moment the wires begin to change their motion; w_1 goes down, w_2 goes up. With this change of motion there comes the reversal of the electric pressure; w_1 becomes negative, w_2 becomes positive. The current in the armature reverses; but just at this moment the split ring changes connections—b_1 begins to touch r_2, b_2 begins to touch r_1. Hence the current still flows in the external conductor w from b_1 to b_2. In other words, the split ring has "commutated" the current, and so enabled it to have a continuous direction in the external wire.

This split ring is called a two-part commutator. If there are four wires or coils on the armature a four-part commutator is required. In Fig. 29 there were 32 convolutions of wire, and an eight-part commutator —four convolutions to each separate coil. The action of these more complex forms is much the same as that of the simple one containing two parts, as just described. It will be easy now to understand the following statement as to the action of a commutator: it serves to reverse the connections between the brushes and the armature wires just at the time when the current is being reversed in them. Referring to Fig. 29 once more, and remembering that it is rotating in a clockwise sense, notice that any coil is differently joined to the top brush before and after it gets to the top.

Before it gets to the top *its advancing* end is joined to the top brush. After it has passed the top

its retreating end is joined to the top brush. Hence its positive end is always joined to the top brush. The work of the commutator may therefore be summed up in the statement that it changes the alternating current of the armature so that its two reversed parts flow in the same direction in the external conductors.

There is a popular impression that the electric current is produced by the friction of the brushes on the commutator, but this is quite erroneous. The electric pressure and the current are due to the action of the magnetic flux on the electrons in the moving conductors, and this alternates in direction. The sole purpose of the brushes and commutator is to commute this alternating current—that is, to make the second half flow externally in the same direction as the first.

Excitation of a Dynamo Magnet—Series and Shunt Machines.—So far we have ignored the excitation of the dynamo magnets, but must now explain how this is done.

In Figs. 39*a* and 39*b* there are two dynamos, differing only in the way the magnets are excited. In Fig. 39*a* the field magnet coil is in series with the armature—that is, the current flowing through the armature must also flow through the field coil. Suppose the top brush is the positive. The current leaves it and passes through the magnetising coil, and then through the external circuit back to the bottom brush. This dynamo is therefore called a series-wound dynamo. The other machine is called a shunt dynamo, because the exciting current is shunted from the external circuit and forms a mere fraction of it. Fig. 39*b* gives the diagram. Suppose 100 units of current circulate, leaving the armature by the top brush. On arriving

at the point *s*, this armature current will divide, about 96 amperes flowing through the external conductors and about 4 amperes flowing through the field coil. These branch currents reunite at the point *r*, flow into and through the armature, and so reach the point from which they started. The field coil is therefore a "shunt" on the external circuit.

The reader may ask, first, why only 4 per cent. of the current flows through the shunt coil. The reason is that its resistance is much greater than that of the

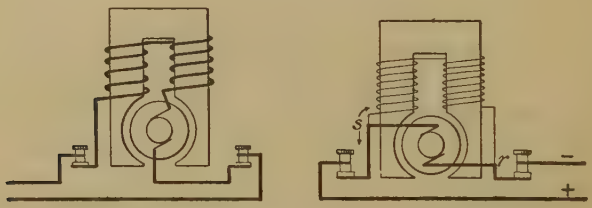


Fig. 39.—Series and shunt dynamos.

external circuit; it is made of fairly fine wire, and there is a great length of it on the coils, both facts conducing to increase the resistance. Thus, when the point *s* is reached there is much more facility for the flow (or what is the same thing, less resistance) through the external conductors than through the shunt coil.

A second question asked is: How can such a small current excite the magnets? If this shunt machine were treated as a series the whole of the current would go through the magnetising coil, instead of the 4 per cent. used here. The answer to this is: The exciting value depends on the current, but not on the current only. It also depends on the number of times

the current is led round the iron cores. In the series machine this may be about 300 turns, whereas in the shunt machine it may be as high as 4,000 turns. Thus the extra turns make up for the weaker current.

How Dynamo Action Begins.—A puzzling question arises in starting a dynamo. We have said that the magnet causes the electric pressure, and that the consequent electric current excites the magnet. Which of them begins the action? The magnet is the earlier stage. When a dynamo is made it is pretty certain that the iron parts will have some slight magnetism. If not the machine will not work, and a magnetising current must be sent through its coils. When once it has been magnetised it always *retains* a slight percentage. Therefore, when a dynamo is started running after a rest its residual field, although weak, sets up a slight pressure on the electrons and gives a slight current. This increases the magnetism, and therefore the pressure and current. So they go on increasing each other till the iron is saturated, and magnetisation has its maximum value. The magnet being fully magnetised, the voltage or pressure is fixed, unless the speed is altered. The current depends in part on external conditions.

Measurement of an Electric Current by its Effects.—A dynamo sets up a certain electric pressure, as we have seen, by separating some of the electrons in its armature. We shall presently say something more of this pressure; meanwhile, what about the electric current? What will be its value, and how is it measured?

The value or magnitude of a given current can hardly be understood till we show how it is measured; therefore, let it be noticed that all the measurements

depend on one or other of the effects that an electric current produces. These are five in number :—

1. A heating effect, as illustrated in furnaces, lamps, etc.
2. A magnetic effect, as in electromagnets, dynamos, etc.
3. A chemical effect, as in electroplating.
4. A mechanical effect, as in motors.
5. A physiological effect, as in shocks, etc.

Each of these may serve as a means of measuring the magnitude of the current, though some are much better than others. Perhaps 3 and 4 are the most accurate. But before we can properly appreciate the ideas involved in the matter we must grasp the true meaning of the word "current." Only then can we see that our measurement carries out the principles involved. We have to distinguish between *different ideas*. It is a very common mistake to confuse "quantity of electricity" with current, or to think that a "Board of Trade unit" is a unit of electricity. As a matter of fact, we have to define what we mean by a "quantity of electricity," by a given "current of electricity," by the power it exerts, etc.

By a "quantity" of electricity is meant a certain number of electrons; by a "current" is meant their rate of flow. But the rate of flow is measured in a particular way, and this not the one which first occurs to an ordinary man. The point is of importance, and will be illustrated by referring to well-known facts.

Speaking of a water stream, a man will say : "The current is very strong; *it runs twenty miles an hour.*" In this way of measuring, a current is estimated by the speed at which the particles of water happen to be travelling. To this there is the great objection

that the value of the same current will change with a mere widening or narrowing of the channel. If the width of the channel doubles, the particles of water move only at half the previous speed, which is now ten miles per hour, although a similar stream of water passes. Hence this method is a false way of stating the strength of the current. Consider Fig. 40, in which some water-pipes have a varying cross section. Suppose that a certain current is flowing through them, say 10 gallons of water per second. Every second 10 gallons enter at the left; 10 gallons leave

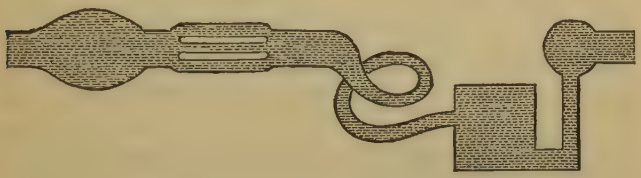


Fig. 40.—Flow of water through pipes.

at the right; and 10 gallons pass through *any given cross section.* (Notice that the 10 gallons leaving are not the *same* 10 gallons that enter in the same second.)

These statements being true, the current, or rate of flow, is the same at all sections of the tube, although the particles of water move more quickly in the narrow parts of the tube than in the wider. For engineering purposes, the rate of flow is the important thing, and this is given for water in *gallons per second,* and not in the speed of particles.

Examining this phrase, "gallons per second," it is seen to consist of a "quantity" of water = gallon, and a time = second. The unit current is 1 gallon per second, one unit of water in a unit of time. A current of strength or value 2 is one of twice the unit value = 2 gallons per second.

It is on these lines that a current of electricity is estimated. The unit current must be one in which *unit quantity passes in* 1 *second.* A very natural unit would therefore be 1 electron per second, in which 1 electron is taken as the unit quantity of electricity. But this is too small for practical purposes. If it be used, the current through an ordinary glow lamp would be 6,000,000,000,000,000,000 electrons per second—a figure which is unwieldy. It would be like giving the water current in atoms of water per second instead of gallons per second.

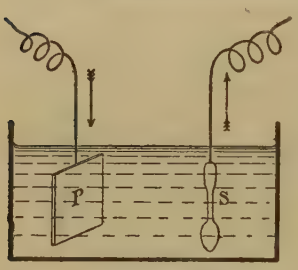


Fig. 41.—Depositing silver by electric current.

To get a reasonable practical value for the unit current a much larger quantity of electricity is chosen as the unit. This *unit quantity is called the coulomb.* It is equal to 10,000,000,000,000,000,000 electrons. The practical way of defining it is a simple one, and depends on well-known facts, namely, the ability of a current to deposit metals like silver from certain solutions.

We will first describe the process, and, in order that it may be more familiar, will use a spoon to receive the deposited silver. In Fig. 41 a spoon S is shown hanging in a liquid which contains silver dissolved in it; the spoon is connected with the negative terminal of a battery. A silver plate P is joined to the positive terminal of the same battery. When the circuit is complete a current flows through the silver solution and deposits silver on S. At the same time it eats silver away from P, so that we may say that the positive electrons carry silver with them as they

flow from P to S. Experiment shows that each electron which flows through the liquid deposits a given amount of silver, so that the weight of silver deposited becomes a measure of the quantity of electricity which passes. All that has to be done is to weigh the spoon before and after the experiment. The difference in weight tells us the quantity of electricity employed. In other words, a quantity of electricity is determined indirectly by weighing the silver deposited by it. Knowing this, it is easy to determine what weight of silver is deposited by the unit of electricity called the coulomb.* Careful experiment shows that the weight is about $\frac{1}{58}$ grain, so that 58 coulombs of electricity deposit 1 grain of silver; 1 pound of silver deposited = 406,000 coulombs of electricity.

In electrical measurements it is more usual to employ the metric system of weights, etc., and to say, therefore, that 1 coulomb deposits $\frac{1}{900}$ gramme of silver, or 1 gramme indicates that 900 coulombs have passed. To quote exact figures, 1 coulomb deposits 0.0011182 gramme of silver. For a form of coulomb meter used by supply companies see pages 75, 76.

Unit Current: the Ampere.—Taking 1 coulomb as the unit quantity of electricity, the unit current follows at once: it is one in which 1 coulomb passes per second. Thus we may speak of the current through a glow lamp as ½ coulomb per second, meaning that ½ coulomb of electricity passes every second that the lamp is glowing.

However long the lamp may work, the rate of flow is the same. Notice, however, that while the current

* The quantity called 1 coulomb (= 10 trillion electrons) was first decided on in a different way, and its value in silver determined subsequently. For accurate work the silver is deposited on a platinum dish, the solution containing 20 per cent. of silver nitrate.

continues constant, the quantity passed through increases with the time. Thus, in

1 second	the quantity passed is	½	coulomb
2 seconds	,, ,,	1	,,
10 ,,	,, ,,	5	coulombs
60 ,,	,, ,,	30	,,

Electrical engineers are not in the habit of specifying the current as so many coulombs per second; a shorter name is employed. The unit current is known as 1 *ampere*, the one word *ampere* being equivalent to *coulombs per second.*

Thus the ampere is a current or a rate of flow: the coulomb is a quantity. The coulomb is akin to a pound or *gallon* of water; the ampere is akin to a *gallon per second.*

Measuring Currents in Amperes.—The electroplating bath measures quantities of electricity. If we desire to find the value of a current we must use a clock or watch along with the electroplating bath. For the silver (or copper) deposited tells us how many coulombs have passed, and the watch tells us how long they were in passing: from the two we can tell the current—that is, how many coulombs passed each second. For example, let the silver deposited be 1.333 gramme—1 gramme = 900 coulombs: therefore 1.333 gramme = 900 × 1.333 = 1,200 coulombs of electricity passed. This is the quantity of electricity.

But the watch showed that the current was flowing for 10 minutes = 600 seconds, so that we know 1,200 coulombs passed in 600 seconds. Dividing 1,200 by 600, we find that the rate of flow is 2 coulombs per second. The current, therefore, is 2 amperes.

This process for measuring current comes naturally out of the method for measuring coulombs, but there

is one objection to it for ordinary purposes: it takes too much time. Several minutes are required to get enough copper or silver for weighing purposes, and that is more time than can always be given. What is wanted is some method that indicates the value of the current at once. An instrument which will do this is called an ampere-meter, though the word is now always abbreviated into ammeter.

A simple ammeter which is very easily made will now be described. It will indicate an approximate value of the current, and so help those who otherwise can get no information.

Simple Ammeter.—This is intended to give a rough idea of an instrument which anybody can make

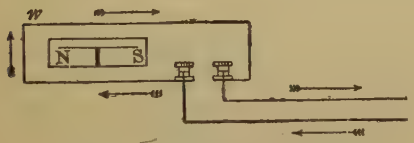
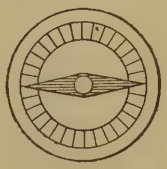


Fig. 42.—Simple ammeter elevation.



Plan of compass.

and use for approximate results. On a board 8 inches by 6 is fixed a piece of stout copper wire *w*, bent as shown in Fig. 42. In the elevation, the top part of the wire is 2 inches above the bottom. In the middle of this is a short compass needle N S, pivoted on a needle point. When a current passes through *w*, the compass moves over a degree scale which serves to show how far the needle is deflected from zero.

The instrument is placed on a table, and the compass sets north and south. This direction is noted, and the base then gently turned round until the needle lies under the upper half of the wire, and the needle is at zero. A current being now sent through the

apparatus, the needle is deflected, the pointer moves a certain number of degrees, and then comes to rest. From this angle, some idea of the current can be obtained. The following table is a help if made to the dimensions shown :—

Deflection	5°	10°	15°	25°	40°
Amperes	0·1	0·2	0·4	0·7	1·0

These values are probable values, and depend on the instrument being used in an ordinary house with no iron or magnets near. If necessary, it can be "calibrated" by sending a series of currents through it and also through a silver solution. The latter, with a watch, determines the value of each current, and the deflection it produces on the simple ammeter is noticed and written down while the experiment is proceeding.

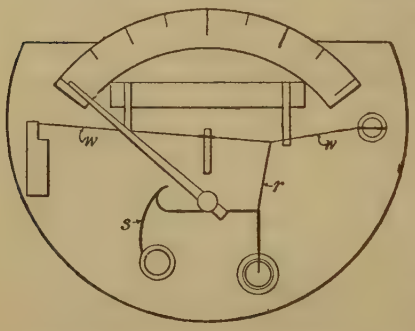


Fig. 43.—Hot-wire ammeter.

Hot-wire Ammeter.—A hot-wire ammeter is represented in Fig. 43. The current to be measured is passed through the thin platinum wire *w*, and heats it to varying degrees depending on the value of the current. The expansion which results causes it to yield under the action of the thin spring *s*, which keeps *w* taut. The thread which connects *s* to the wire *w* (through the connecting wire *r*) passes round a pulley and pulls the pointer more or less according to

the expansion of *w*. In this way the heating effect of a current is made to indicate its own value. The instrument is furnished with a calibrated scale as described.

A "Force" Ammeter.—An ammeter known as the Weston depends on the force which a current experiences when it flows through a magnetic field. Figs. 44*a*, 44*b* show the rough elevation and plan.

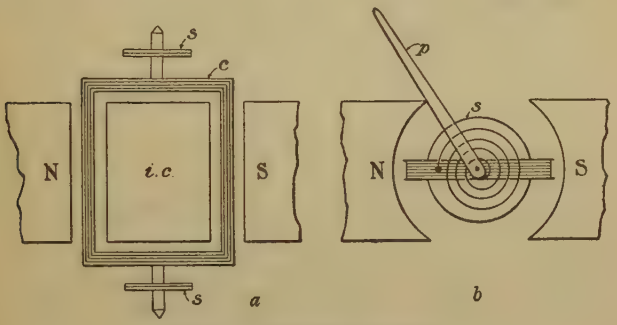


Fig. 44.—Weston ammeter.

a, elevation; *b*, plan.

A coil *c* is pivoted and held by two spiral springs *s s* so that it lies between the poles of a magnet N S, an iron core *i c* being supported in the middle of the coil so as to strengthen the magnetic field. The current is led into and out of the coil by means of the spiral springs, and is twisted by the magnetic field, carrying the pointer *p* over an angle which shows the value of the current. Stronger currents twist the coil and the springs through a larger angle than weaker ones.

CHAPTER III

HOW ELECTRICITY DOES WORK—MEANING OF THE WORD "VOLT"

In the last chapter we have explained the meaning of electric currents; we now approach the question: How are the currents related to work? This is a most interesting problem, but again we must clarify our ideas. To an ordinary man the question, "How does electricity work?" means, "How does electricity move machinery or tramcars?" But the engineer requires a more searching statement. An electric current exerts force in a motor because of the powerful magnets it creates and the consequent magnetic attraction. In a lamp, electricity creates light and heat because of the friction to its motion. In electroplating the current does work by dragging one atom from another. These answers (which will be amplified in succeeding chapters) suggest how the work is done in the ordinary sense of the word. But the question here asked is this: What does electricity lose when it does work? We have seen that it cannot be destroyed. The electrons that come to a motor pass into it and through it; as many pass away as come to it. But if that is so, they must have lost something.

When steam does work in an engine it loses heat. Its temperature falls, and the heat lost is *transformed* into work. When compressed air does work, *it loses compression.* The air is not changed, but the air which leaves the engine after doing work is expanded: it is

no longer the *compressed air* which entered. Again, when water does work in a water-wheel, it loses elevation or height. It was *above* the water-wheel; now that it has done its work, it is *below*, and the working power has gone out of it.

These are the ideas involved when we ask the question: How does electricity work? The hasty thought or assumption is that it is consumed like fuel. But we have already disproved that, and we are left to ask: What change comes over the electrons as they do their work? The answer is this: A dynamo or battery puts electricity in a state comparable with compression (of air) and with elevation (of water), or with a heated condition (as in steam). In the case of electricity it is not called compression, or elevation, or temperature, because, strictly speaking, these ideas are not correct. The name used in the electric case is voltage.

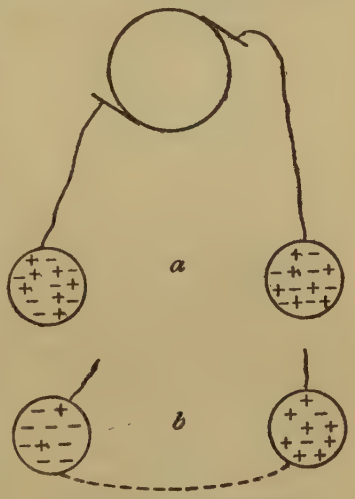


Fig. 45.—Dynamo terminals.
a, before starting; *b*, while running.

Picture the terminals of a dynamo. Before it begins to run they are as in Fig. 45*a*—equal quantities of electricity everywhere and no pressure. When it runs, they are as in Fig. 45*b*—an excess of positive is compressed on one, an excess of negative on the other. Their self-repulsion and mutual attraction at once give

them *working ability*. If a conductor be provided (as in the dotted line, Fig. 45*b*) the electrons will expand along it ; the pressure will fall as they go. It is on this fall of pressure that we have to fasten our attention, for it is the master-key to all the ordinary working relationships. Let us form a picture so far as we can, and

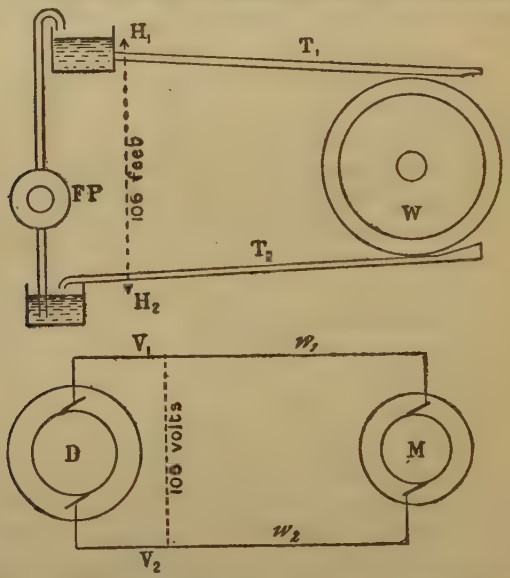


Fig. 46.—Force pump and water-wheel compared with dynamo and motor.

choose an analogy which will bring the points boldly before the mind. On the electrical side we choose a dynamo working a motor. On the material side we choose a water force pump working a water-wheel. Fig. 46 gives a rough diagram of it.

1. FP is the force pump raising water through the height H_1 H_2.

1. D is the dynamo raising electricity through the voltage V_1 V_2.

2. The same thing may be put in another way. The force pump FP is separating water from the earth, and the earth and water will attract each other back.	2. The same thing may be put in another way. The dynamo is separating positive and negative electrons, and they will attract each other back.
3. The water flows back through T_1 to the water wheel W, and then through T_2 to the pump again.	3. The positive electrons flow back through w_1 to the motor M, and then through w_2 to the dynamo again. (As already stated, in talking of the current, we speak only of the positive electrons so as to simplify the statements.)
4. A certain *quantity* of water is raised every second and flows back every second. This quantity is measured in pounds, say 3.	4. A certain *quantity* of electricity is raised every second and flows back every second. This quantity is measured in coulombs (as already explained), say 3.
5. The current is 3 pounds per second.	5. The current is 3 coulombs per second (known as 3 amperes).
6. The work done by water as it falls depends on the quantity of it and also on the height H_1 H_2. If H_1 H_2 = 106 ft., each pound of water does 106 ft.-lb. of work.	6. The work done by electricity as it falls, depends on the quantity of it and also on the height V_1 V_2. If V_1 V_2 = 106 volts, each coulomb of electricity does 106 volt-coulombs of work.

(The reason for choosing this figure 106 will appear presently.)

In making these parallel statements the subject is easy till the last line is reached, and then the idea of the volt as a unit is apt to puzzle the reader. Let us turn aside to see what this means. To begin with, notice that work is the same thing whether done mechanically by water or electrically by a motor. It requires a certain amount of work to grind 100 pounds of corn, and if done by the water-wheel it is measured

in foot-pounds. Let us say it requires 1,000 foot-pounds of work. We could get this by 100 pounds of water falling 10 feet in a water-wheel, or by 10 pounds falling 100 feet, or by 50 pounds falling 20 feet.

Suppose, however, that it were done by an electric motor, what work must be done? Evidently the same 1,000 foot-pounds. But in electric measurements the *unit* of work is not a foot-pound, but the analogous value—1 volt-coulomb. Measured in volt-coulombs, the figures would not be the same. Experiment shows that the motor would take 1,356 volt-coulombs of work, so that

1,356 volt-coulombs = 1,000 foot-pounds.

Notice that we cannot translate coulombs into pounds: quantities of water and quantities of electricity are incommensurable. So also are electric and gravitational pressures: we cannot translate height into volts. *Yet we can translate volt-coulombs* into foot-pounds, because they are of the same nature. Each of them is a unit of work differing only in numerical value from the other.

1 foot-pound = 1.356 volt-coulombs of work.

Take a very simple problem. In going upstairs to bed, the writer has to do work in lifting himself by the muscles of his leg. The amount of work is 1,950 foot-pounds, for his weight is 150 pounds and his bedroom is 13 feet above the ground: and $150 \times 13 = 1{,}950$ foot-pounds. The working ability necessary for this is obtained by burning a certain amount of muscular tissue in his legs. But the writer could be raised by a lift, or by an electric motor, and the work would be the same in each case. It is easy to say what would

be the electrical equivalent of the work—1 foot-pound = 1.356 volt-coulombs: therefore 1,950 foot-pounds = 1.356 × 1,950 = 2,643 volt-coulombs. If the motor is run at 100 volts, then 26.43 coulombs of electricity must pass through it before it can lift me upstairs. Each coulomb falling through the motor will do 100 volt-coulombs of work, and 26.43 coulombs will do 2,643 volt-coulombs of work.

If the reader asks what current is needed, the answer cannot be given, because it may be almost any value. A powerful motor, taking a stronger current, will do it in less time than a smaller machine. For example, the current may be 1 ampere—that is 1 coulomb per second. Then it will be 26.43 seconds before 26.43 coulombs have passed, and that will be the time required to get me upstairs with this current. But suppose the current is 10 amperes = 10 coulombs per second, then 26.43 coulombs will pass in 2.643 seconds, and I shall be upstairs in less than 3 seconds.

Thus, if the voltage is kept the same, any current will do, a strong current doing the work in a shorter time, a weak current taking longer. The thing that is constant is the 2,643 volt-coulombs. If the motor were run at 200 volts, the quantity of electricity needed would be only 13.21 coulombs, half as much as with 100 volts.

From all this it is easy to see that a volt is a unit of electric pressure, and that it is also a unit of working ability. Every coulomb of electricity put under a pressure of 1 volt can thereby do 0.7373 foot-pound of work. That is:

1 volt-coulomb = 0.7373 foot-pound.
1 foot-pound = 1.356 volt-coulomb.

We may now resume our parallel statements—

7. The pump FP (Fig. 46) lifts each pound of water 106 ft., putting into it 106 ft.-lb. of work.	7. The dynamo D lifts each coulomb of electricity 106 volts, putting into it 106 volt-coulombs of work (= 78·17 ft.-lb.).
8. The water falls 3 ft. in the tube T_1, 100 ft. in the water-wheel W, and 3 ft. in the tube T_2.	8. The electricity falls 3 volts in the wire w_1, 100 volts in the motor M, and 3 volts in the wire w_2.
9. The work done on the wheel by each pound of water is 100 ft.-lb.; the rest is wasted in the conduits.	9. The work done on the motor by each coulomb of electricity is 100 volt-coulombs (73·73 ft.-lb.). The rest is wasted in the conductors.
10. If the water were raised 212 ft., each pound of water would serve for twice as much work.	10. If the electricity were raised 212 volts, each coulomb would serve for twice as much work.

From these statements it is easy to see that one volt is used as a unit of pressure,* and also as a unit for measuring the work put into each coulomb of electricity. As the idea is difficult, and as repetition is helpful, the following comparison with air is added:

11. Unit quantity of air is 1 lb. In the atmosphere it exists under a pressure of 15 lb. on the square inch.	11. Unit quantity of electricity is 1 coulomb. In ordinary conductors it exists under a pressure unknown.
12. It can be given working ability by a force pump.	12. It can be given working ability by a dynamo or battery.
13. To put 1 ft.-lb. of work into each pound of air, the pressure must be raised to 17·5 lb. per square inch, or about 2·5 lb. per square inch above ordinary pressure.	13. To put 1 volt-coulomb of work into each coulomb of electricity, the pressure must be raised to 1·356 volt, that is 1 volt above the unknown ordinary pressure.

* Strictly speaking, not a unit of pressure, but of difference of pressure. Two terminals are at different pressures, and the difference is measured in volts.

14. The 2·5 lb. per square inch is the important figure. It is difference of pressure that counts; that is, the difference between compressed and uncompressed. Wherever a current of air flows we can measure the working value in each pound as it passes from one point to another.

14. The excess pressure is the important idea. It is difference of pressure that counts: that is, the difference between the ordinary state and the special. We can measure the working value of a coulomb flowing between any two points.

A careful reading of these comparisons will make the meaning of a volt and of any number of volts more or less easy to grasp.

How an Electric Current is Controlled.—The control of an electric current is generally taken to be a mysterious matter, but such an impression arises because the conditions are overlooked. Consider the case of gas or water; the control of the current depends first on the pressure urging it forward, and secondly on the resistance of the path along which it is permitted to flow. Thus the so-called control of the current resolves itself into the control of the pressure, or of the resistance, or of both.

It is the same with electricity. To control the current means that we must control the electric pressure (the voltage) or the resistance of the conducting path offered to the electricity.

Consider Fig. 47, where D is to represent a dynamo and *w* a wire connecting its terminals. Let us suppose that D gives an electric pressure of 10 volts, and that *w* consists of copper wire No. 16 and having a length of 256 yards. Such a wire offers a definite resistance to the flow of electricity, known as 2 ohms. Under these conditions the current would be 5 amperes (5 coulombs per second),

neither more nor less. The reason for saying this will appear afterwards.

Suppose now that the dynamo armature is run at twice the speed, so that the wires on the armature cut through the magnetic field at twice the rate. The pressure is thereby doubled, and equals 20 volts; this increased pressure at once doubles the current, which becomes 10 amperes.

If the speed be reduced, the voltage at once drops

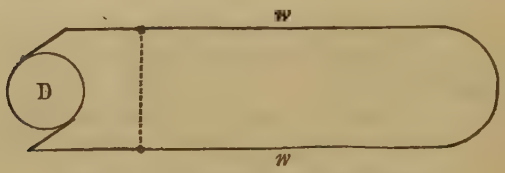


Fig. 47.—Dynamo and wire circuit.

in proportion, and the current at once automatically responds to it. These experiments show how the current can be controlled by varying the pressure.

Control of Current by Resistance.—The second way of controlling the current is by making changes in the conductivity of the conductors, for if this be done the current flowing will alter, even though the pressure be kept constant. There are many ways in which conductivity can be altered, but we shall be wise, in dealing with them, to follow the usual practice and to speak, not of conductivity, but of resistance. Instead of saying that a wire has a high conductivity, it is said to offer a small resistance. A substance whose conductivity is low is said to have a high resistance. Resistance is, in fact, the converse of conductivity. Now the 256 yards of No. 16 copper wire spoken of in the preceding section have a certain definite resistance known as 2 units, or 2 ohms. This means that

there is a recognised unit of resistance, called 1 ohm—so named after the German physicist, G. S. Ohm, who first proclaimed the laws which control the value of an electric current.

Let us, therefore, take our dynamo giving a pressure of 10 volts, and the 256 yards of No. 16 copper wire. The current is, as we have seen, 5 amperes. Keeping the speed constant, and therefore keeping the voltage = 10, let the wire be cut in two and only 128 yards used. *The current automatically doubles*, the reason being that the *resistance* to the flow of the electrons is *halved*. The 128 yards have a resistance of only 1 ohm.*

If twice the length of wire had been used (512 yards) the current would automatically fall to half its first value, because the resistance had been doubled.

Or, again, if instead of using 256 yards of copper wire an equal length of similar iron wire be used, the current falls to one-sixth, because the iron offers so much more resistance to the flow of electrons than does an equal length of copper.

It will be noticed that when the resistance changes, the resulting change in current is in the inverse way: an increase in resistance causes a fall in current.

The following explanation is very useful. When wires are added together end to end, they are said to be in series with each other, and their resistances are *added* together. The current through one is the same as the current through all. When wires are fixed side by side (with ends joined together) they are said to be in parallel, and if they carry a current it divides among

* The resistance is of unit value when a given voltage produces a current of equal numerical value in amperes. Thus if 15 volts produce a current of 15 amperes, the resistance of the circuit is 1 ohm. One and a half volt would produce 1½ ampere.

them. They act like one wire of greater diameter, and therefore offer less resistance than any one of them.

Ohm's Law.—The whole of this question about the control of the current is summed up in a statement known as Ohm's law. It simply declares that the current is proportional to the voltage (rising or falling with it), and also inversely proportional to the resistance (rising as resistance falls, and falling as resistance rises). It is usual for electrical engineers to calculate the value of the current flowing by means of the following equation based on Ohm's law. Current in amperes = pressure in volts ÷ resistance in ohms: 1 ohm is the unit of resistance, and other resistances are measured by it.

It will now be easy to illustrate two practical methods by which the value of a current can be changed.

An Installation of Two Lamps.—There are two ways in which two lamps may be joined to a dynamo: these ways are known as the "series" and "parallel" methods respectively. They are shown in Fig. 48, *a* and *b*.

In the series arrangement, one lamp filament practically forms a prolongation of the other. Electrically, it is the same as if the first lamp had had its filament doubled in length. Consequently, there is twice as much difficulty in the path which the current must take, and the two lamps in series reduce the current flowing to half the value it would have if only one lamp were in circuit.

This reduction of current when the second lamp is put in circuit is often ascribed to the fact that the first lamp has "consumed" half the current and left only half for the second. Let it be noted that the reduction occurs in every part of the circuit, and that

here, as in all other cases, there is no such thing as "consumption." With two lamps in series the current flowing from the dynamo is half what it would be with one, because the resistance of the circuit is doubled: the dynamo, the two lamps, and all other conductors

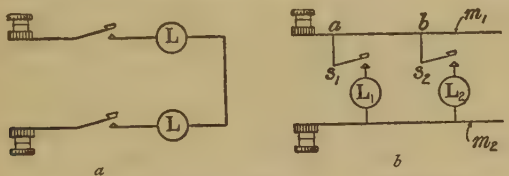


Fig. 48.—Lamps in series (*a*), in parallel (*b*).

have the same current flowing in them, though only half the value possessed by the current in the first case where one lamp only was used.

Lamps in Parallel.—The second method of arranging two lamps is the "parallel" system, and is the one generally employed. The diagram Fig. 48*b* shows dynamo terminals, a positive main m_1 and a negative main m_2. *The two lamps are independently joined to the two mains.* If the switch s_1 is opened, the lamp L_1 is cut out of circuit, but L_2 is not affected, and continues to burn. In fact, L_1 and L_2 form *branch* circuits across the mains, and, speaking generally, do not interfere with each other. Let us suppose that each lamp, when joined to this dynamo, takes a current of 1 ampere exactly, and let us also suppose that only one lamp L_1 is joined to the dynamo. The current in this lamp, and also in the machine, is 1 ampere. There is no current through the other lamp L_2. Now let L_2 be switched on, L_1 being kept joined as before. The second lamp L_2 now forms an additional path between the positive and negative terminals of the dynamo, and the current through it is also

1 ampere. Each lamp is therefore getting a unit current, and each unit flows from m_1 to m_2. It is evident, therefore, that the current leaving the dynamo is 2 amperes, and that this double current in m_1 divides at the point *a*, one ampere going through L_1, the other ampere passing from *b* through L_2.

The principle is the same as that by which water is supplied to houses in a town. We may say that there are two water mains in the town. One is called the water main, and serves to bring water into the houses; the other is called the sewer, and serves to carry the water back to river and sea (whence it came). Each house has its water-pipes in parallel between these two mains. We may imagine that three householders turn on taps so as to get similar currents, and that each one takes unit current, say one pound of water in one second. Then the current in the water main will be 3 units (3 pounds per second), which will divide between the three houses, and reunite in the sewer.

It is obvious that each one of the houses may take a different current and yet the above be practically true. By turning on the taps to different degrees, the first house may take 1 pound per second, the next house 3 pounds per second, and the third house 7 pounds per second. Then the main current will be $1 + 3 + 7 = 11$ pounds per second, which will divide between the branches in proportion to the conducting facility they offer.

From this the reader will gather that in a row of shops taking electric energy from the mains of a supply company, each shop will independently take such currents as it requires. This is done by the parallel system; the mains are kept at a constant pressure by the company, and the value of the current which then flows depends on the conducting facility which anybody

provides by joining lamps, etc., across the mains. The more lamps in parallel the less their joint resistance (that is, the greater their joint conductivity), and hence a greater current automatically flows.

House Installation. — We may now explain how the wiring scheme of an ordinary house is arranged. Let it be supposed that the supply comes from a company whose mains are laid under the pavement. They attach two short conductors to their street mains, and bring them into the house, where they are joined to

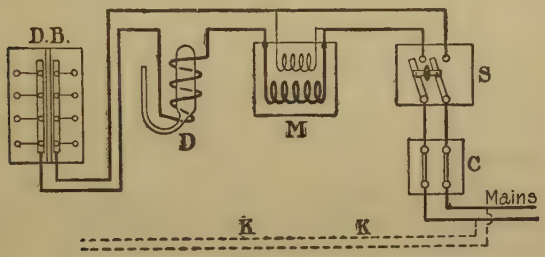


Fig. 49.—Devices used in electric installation.

the following pieces of apparatus, shown diagrammatically in Fig. 49:—1st, a double pole main fuse or cut-out C; 2nd, a double pole main switch S; 3rd, a meter M; 4th, a maximum demand indicator D; 5th, a main distribution board D B. All these will be referred to later, but before proceeding a few words may profitably be said about them here. In C are two tin wires, which are intended to protect the installation against excessive or dangerous currents. A cut-out is of much less value when inserted in one main only, hence the double "pole" fuse. The switch S is made to break the circuit, and the break is made in both mains, so as to ensure greater certainty and safety.

The meter M carries the current. Speaking generally, that is all that is necessary, so that one main only need go to and from it. Sometimes there are reasons for adding a second coil joined across the mains, and to indicate the voltage or pressure. The maximum demand indicator depends on the current only, and therefore is inserted in one main. The distribution board is the starting-point for the house wiring.

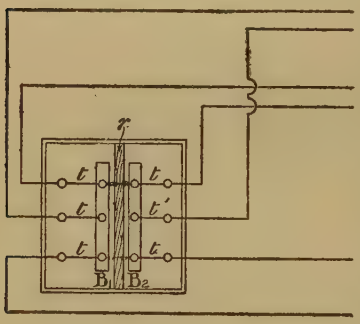


Fig. 50.—Distribution board.

In Fig. 49 a couple of branch mains K K are indicated by dotted lines. These are for supplying the kitchen, etc., with power for heating and motor purposes, and will only be found in larger houses. A special meter would be inserted in these, and the energy taken through it is paid for at a lower rate. It is known as a "heating" or "power" or "basement" circuit.

Distribution through the House.—Fig. 50 is a front view of the distribution board; B_1 B_2 are the positive and negative bus bars, with a porcelain insulating ridge *r* between them; *t t* are tin fuse wires, each of which will carry the normal current of the branch circuit connected to it, but will melt and disconnect the branch if any accident happen which threatens danger to the conductors. The branch mains go from the terminals to which the tin wires run. In some cases the fuse wires are fixed in porcelain bridges which span from B to the terminals.

From these terminals wires are run in couples (+ and −) to a subsidiary board on each floor, and from this to the lamps. All the lamps are in parallel, and each circuit is protected by a fuse. Each small group of lamps can be completely disconnected by removing the fuse wires controlling it.

Short Circuit.—This arises when one of the mains is brought into contact with the other, either directly or by a good conductor. The resistance is then so much diminished that the resulting current may be strong enough to make the mains, etc., red-hot and bring about a fire. Fuses prevent this. A strong current melts them before the copper wires get red-hot, and the circuit is broken. The dotted line in Fig. 47 (page 68) suggests a short circuit.

Electric Meter.—The electric meter employed varies very much, but we shall describe a well-known one which is a form of electroplating device like that used for silver. The metal deposited is quicksilver or mercury, and it is arranged that the deposited metal shall not adhere but fall in drops from the receiving plate into a glass tube. As it collects in this it indicates by its height how many coulombs of electricity have been supplied to the house. In Fig. 51 the containing vessel is seen, with a pool of mercury in an annular channel at the top to form the "loss" terminal. The current enters the instrument here, and the mercury is dissolved according to the quantity of electricity which passes through the liquid (a phosphate of mercury solution) to the metal cone *p*, by which the current leaves the instrument. The cone *p* is made of a platinum alloy. It has a corresponding quantity of mercury deposited on it, but the mercury does not adhere, and falls in small drops into the tube below. The mercury deposited by each coulomb fills a small

length of the tube. The number can be read on a scale. When 100 coulombs have passed, the mercury siphons over into a wider tube, and there indicates the number of hundreds of coulombs.

By taking note of the supply voltage the instrument scale can be made to indicate the work done, giving this in the number of Board of Trade units. This is a term we must now explain, first showing the difference between power and work.

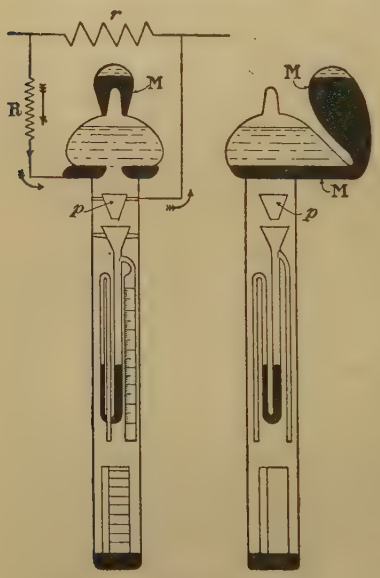


Fig. 51.—Electric Meter.

M, mercury; *p*, platinum cone; *r*, a small and R, a large resistance.

Power and Work.—It is tolerably easy to form a good idea of a piece of work, and to know what is involved. To grind a ton of corn; to go upstairs to bed; to light a concert-hall for three hours; to propel a tram-car five miles: these are all definite pieces of work which have to be done. In practical life, however, it is necessary not only to do the work, but to do it *in a reasonable time and at a certain rate.* Clearly, then, we have a new idea. Besides the idea of work, we have the rate of working, which is called "power." The unit of work (mechanical) is the foot-pound; the unit of power is the foot-pound per

second. The electric units are: work in volt-coulombs, power in volt-coulombs per second.

Engineers commonly use a larger unit of power, equal to 550 ft-lb. of work per second. This is called the horse-power, because it was at one time supposed that a horse could do work at this rate.

One horse-power = 550 ft.-lb. per second, and also = 746 volt-coulombs per second.

As electricians have to employ units of work and power very much more frequently than is usual in mechanical affairs, they have agreed on names which abbreviate the expressions already given. Thus the unit of work = 1 volt-coulomb, is called 1 joule; the unit of power = 1 volt-coulomb per second, is called 1 watt. It follows that 1 joule of work per second = 1 watt; 746 watts = 1 horse-power.

It is exceedingly easy in electrical industry to find what power is taken by any machine or lamp. All that is required is the voltage and the current. Take a lamp, for example. Let it be run at 100 volts pressure and the current = $\frac{1}{2}$ ampere ($\frac{1}{2}$ coulomb per second). The power = 100 × $\frac{1}{2}$ = 50 volt-coulombs per second = 50 watts. Thus power is found by multiplying together the voltage and the amperes.

Board of Trade Unit.—The electric supply companies charge their customers according to the *work* done for them, and the unit of work they employ is called a Board of Trade unit. Its value is shown by the following statements:—

1 B.O.T. unit = 1,000 watt-hours.
,, ,, = 1,000 volt-ampere-hours.

As 1 ampere-hour = 3,600 coulombs:

1 B.O.T. unit = 3,600,000 volt-coulombs.
,, ,, = 2,653,280 ft.-lb. of work.

It will be obvious from this that the B.O.T. unit is not a unit of electricity, but a definite piece of work done electrically. Take now a few examples to see how it works out in practice.

A 16-candle-power lamp runs, say, at 120 volts, and requires a current of 0.5 ampere. Power required is $120 \times .5 = 60$ volt-amperes = 60 watts. In burning 10 hours, it requires $60 \times 10 = 600$ watt-hours of work, or six-tenths of a B.Q.T. unit.

A motor takes 10 amperes at a pressure of 500 volts. Power = $500 \times 10 = 5{,}000$ volt-amperes = 5,000 watts. In 1 hour the work done = 5,000 watt-hours = 5 B.O.T. units. In 6 hours the work done = $5{,}000 \times 6 = 30{,}000$ watt-hours = 30 B.O.T. units.

An electric oven takes a current of 9 amperes for 30 minutes, then the current is reduced to 5 amperes for 1 hour. Voltage = 200. Work done = $200 \times 9 \times \frac{1}{2} = 900$ watt-hours for the first period; and $200 \times 5 = 1{,}000$ watt-hours for the second period. Total work = $900 + 1{,}000 = 1{,}900$ watt-hours = 1.9 B.O.T. units.

The majority of the meters put into ordinary houses have scales which indicate at once the number of B.O.T. units.

Maximum Demand Indicator.—In Fig. 52 there is a maximum demand indicator. It consists of a metallic strip *m* wound round a glass tube containing air. As the current in *m* warms it, the air inside expands, and pushes down a mercury column. The mercury rises in the other limb of the tube, so that some of it reaches the outlet *r* and falls into the other tube *t*. Of course the maximum current will drive over more mercury than any other, so that the height of the mercury in *t* indicates what the maximum current has been since the last visit of the inspector. Any

subsequent current of less value than the maximum does not drive any mercury over, because it does not warm the tube so much.

Many companies base their charges on this maximum current. A little thought will show that two customers might take the same number of B.O.T.

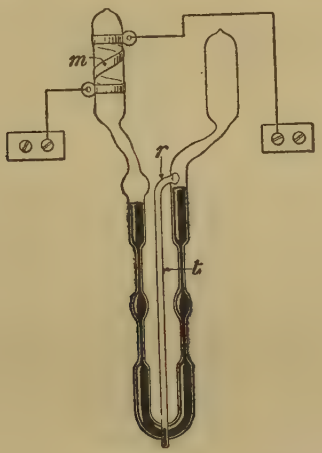


Fig. 52.—Maximum demand indicator.

units, although one had a weak current flowing for 6 hours per day and the other a strong current flowing only for 1 hour. It costs more to supply the second customer because he demands more *power*—the engines, dynamos, etc., must be larger for such a customer. His maximum demand is greater, and he can justly be charged more for the same amount of work done.

CHAPTER IV

ELECTRIC HEATING—FURNACES AND RADIATORS

THIS is the first of the commercial applications of the electric current that we shall describe, and it is chosen because it is, in some senses, the simplest of them all. Moreover, heat invariably results from the passage of a current and sometimes calls for great skill to use it or to avoid it. We have already seen that a given current produces heat in every part of its circuit, but gives more where it encounters most resistance. Let us now take the cases where a high temperature is needed, and show one or two ways of producing it.

Electric Furnaces—1. Resistance Furnaces.—Fig. 53 shows a small electric furnace, consisting of a porcelain tube T, over which is wound a spiral of platinum strip P_1 P_2. This is very thin, and partly on that account and partly because platinum is not a very good conductor, the current experiences a great deal of resistance in flowing from P_1 to P_2. Hence a great quantity of heat is produced in the platinum, and it gets very hot. As it lies very close to the porcelain tube, the latter may be said to be in a red- or even a white-hot jacket, and soon becomes as hot as the metal round it.

It is obvious that any article, such as a crucible, put inside the tube will also be heated up to the same temperature, and that it can be kept heated for any length of time.

The value of this furnace lies in the fact that it

allows a body to be heated in the presence of pure air. No fuel such as gas or coal is burning near, so that the furnace is free from all fumes produced by such fuel.

Of course, a jacket is required to prevent the cooling effect of the air currents which would be set up. The furnace is therefore placed inside a chamber of some heat-resisting material. Very cheap material will suffice. Nicely-fitting bricks do very well if nothing better is at hand.

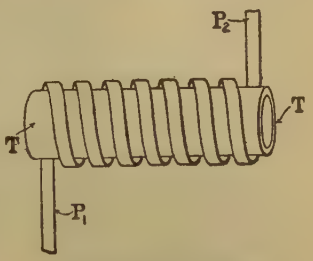


Fig. 53.—Electric furnace.

The only objection to this furnace is its high price, arising from the use of platinum, a metal which is now dearer than gold. Platinum is chosen because its melting point is very high; very much higher than that of any ordinary metal. Its melting point is, indeed, considerably higher than that of iron, and it has a further advantage over that metal in the fact that it does not burn or rust.

A platinum-resistance furnace like that described will give temperatures up to 1,200° Centigrade (2,192° Fahrenheit).* Platinum does not melt till the temperature reaches 1,750° C., but it is not advisable to get too near this, for a little accident might then carry the temperature too high, the platinum would melt, and the furnace be destroyed.

* Temperature is measured in two scales. The ordinary English thermometer is called Fahrenheit, the one used by scientific men is known as the Centigrade scale. The following are equal temperature readings: —

Centigrade	0°	100°	200°	500°	1000°	1500°.
Fahrenheit	32°	212°	392°	932°	1832°	2732°.

A larger furnace of the same platinum-resistance type and one which easily commands temperatures up to 800° or so is shown in Fig. 54. The plugs for connection are behind the furnace and the platinum strip is wound round the furnace chamber. A slab of earthenware, seen at the side, is placed against the opening and encloses the space sufficiently well. The

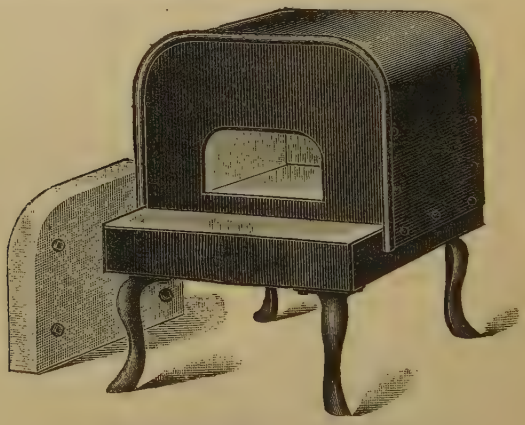


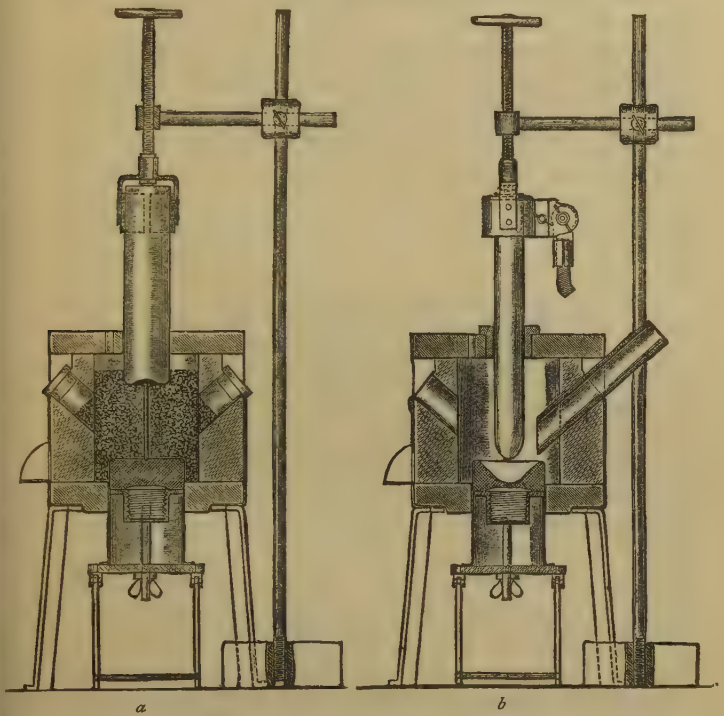
Fig. 54.—Electric furnace. (*Griffin & Co.*)

whole is confined in an iron case, and forms a good example of a convenient furnace.

A cheap substitute for the platinum can be found in wires of nickel or a nickel alloy. These are wound round the body of the furnace chamber or are embedded in its sides. They do not allow such high temperatures as are possible with the platinum furnaces, but if protected from air they will stand 600° to 900° C. In winding the bare wire round the tube which forms the furnace, it is necessary to insulate the convolutions by placing asbestos between them.

A type of resistance furnace in which the resistance

to be heated is a thin pencil of carbon fixed between larger rods of the same substance is shown in Fig. 55*a*. The pencil is seen in the middle, held between the



a *b*

Fig. 55.—Electric furnaces. (*Griffin & Co.*)

a, carbon resistance; *b*, arc.

carbon rod at the top and a carbon block at the bottom. The powdered material which is to be heated is packed round the carbon pencil. When a current of about 40 to 60 amperes is sent through, the carbon pencil

becomes white-hot, and the heat gradually spreads to the surrounding material.

About 50 volts pressure may be required for this furnace, so that the power runs up to about 2,000 volt-amperes (2,000 watts).

2. Carborundum Furnace.—Fig. 56 is a diagram of a furnace in which a very hard material called carborundum is made. Two stout carbon rods C_1 C_2 pass through the walls of the furnace, and serve to lead the current in or out. The furnace is charged with a mixture of coke, sand, salt, and sawdust; but, in packing, care is taken to provide a core of carbon in the space between the two stout rods. The whole is

Fig. 56.—Carborundum furnace.

then covered in. The carbon core is seen in the diagram, and serves to conduct the current in the early stage, the mixture of sand, salt, etc., having little or no conductivity when cold. As the temperature gets high the conductivity increases, and the mixture enters into violent chemical action; the elements begin a fresh combination, some of the carbon escapes as a gas (carbon monoxide), and some of it combines with the silicon in the sand to form carborundum, which is a silicide of carbon. This substance is very hard, and is used instead of emery for grinding and polishing.

Carborundum furnaces are made on a fairly large scale, the materials used for one charge weighing 10 to 15 tons. From this charge 3 tons of carborundum may be obtained.

The electric pressure and current vary. At the beginning the pressure is about 125 volts and the current 1,500 to 2,000 amperes. As the materials grow hot the current increases, and may rise to 5,000 or 6,000 amperes. An alternating current is used.

It is worth notice that the furnaces shown in Figs. 55 and 56 have one advantage over the other forms described. The heat is produced *inside* the chamber in which it is desired. This is a striking feature of many electric furnaces and leads to great economy.

Another kind of resistance furnace consists of a carbon tube, the wall of which serves as the conductor. As the current flows along the tube it becomes very hot indeed, and, as carbon cannot be melted, it is

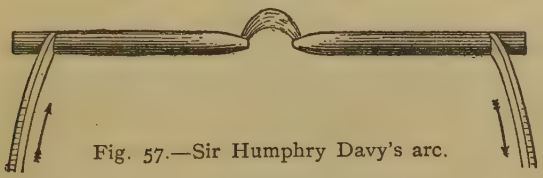


Fig. 57.—Sir Humphry Davy's arc.

possible to get higher temperatures in this way than with any other material—at any rate, so long as resistance methods are employed.

There is still another kind of electric furnace, known as an "induction" furnace. It depends on the action of alternating currents, and lies outside our scope.

3. Arc Furnaces.—In these the heat is produced at a break in the circuit, called an arc. The origin of the word "arc" is very simple. In 1821 Sir Humphry Davy was experimenting with an electric battery, and found that, if in breaking the circuit the broken ends were separated a small distance only, the current continued to flow across the break in a kind of flame; but,

as the flame was very hot, it caused a strong ascending current of warm air, and this partially lifted the electric "flame" and gave it a curved or bowed figure (Fig. 57). Naturally, this was called the electric "arch," but the word was abbreviated to arc, which has continued to be the term employed. The electric arc is generally produced between carbon rods, and is used for a number of furnaces.

In all forms of arc the first thing to do is to bring the carbons together, so as to allow a current to flow. If, then, the carbons be separated, the inertia of the current enables it to jump across the gap as it is being formed. This turns some of the carbon into vapour, and produces such a high temperature that volatilisation is easy. Once started in this way there is no reason why it should not continue, for enough vapour is supplied by the hot ends of the carbon to make the gap between the carbons a sufficiently good conductor. Thus we get a circuit in which there is a break filled by a very small weight of carbon vapour, with a high resistance, conditions which are very favourable to much heat being produced. As a matter of fact, the temperature of the arc is higher than that obtainable in any other way. It is estimated that it rises to about 3,700° C. or 6,690° F. Nearly all substances are melted in the arc, metals are turned into vapour, etc. Practically, carbon is the only substance which will stand the very high temperature, and it is not astonishing to find that many substances can be prepared and others decomposed by the arc, and by that alone.

The general arrangement of an arc furnace may be gathered from Figs. 55*b* and 58, which illustrate an experimental furnace designed by Borcher.

In Fig. 58 the carbons are inclined at an angle of about 90°, and the arc is formed just over the mouth

of a small crucible at the bottom of the furnace chamber. A small stopper at the top can be easily removed, and the material thrown in.

In Fig. 55*b* the arc is formed between a vertical carbon rod and a crucible below it. There is a side

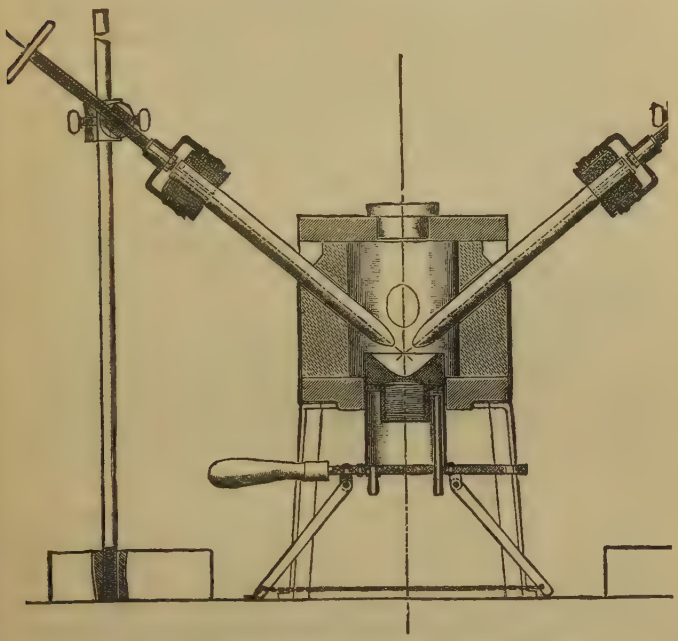


Fig. 58.—Borcher's arc furnace. (*Griffin & Co.*)

tube for introducing material. The furnace body is the same in both cases.

All these arc furnaces are started by bringing the two carbons together for an instant (so that the current may begin), and then separating them by a very short length—say about one-eighth of an inch. The two

carbons consume or are worn gradually away, and they have to be fed forward during the operations. This is done by screws provided for the purpose, or by sliding the carbons through the clamps in which they are secured.

There is one peculiar feature of an arc furnace which may be mentioned here. It is possible to change the position of the arc without opening the furnace, simply by placing a magnet in a suitable position *outside*. The "field" of the magnet, penetrating through the walls, can be made to push the arc up or down or from one side to the other—of course, within certain narrow limits. This is often of great service if the heating is irregular. Some furnaces are provided with mica windows to facilitate observation of the interior.

If the arc is extinguished for any reason, it can be started again only by bringing the carbons together for a moment, as at first. The electric pressure employed is too low to break through an air gap, but, when once the current is started, the vapour formed in the arc constitutes a sufficiently good conductor.

Electric Heaters. — In electric furnaces the object is to get a high temperature, and, as we have seen, this object is achieved very successfully. When the highest possible temperature is required, the electric furnace has no competitor. But this can no longer be said when it is desired to obtain large *quantities of heat*. In warming a room, or boiling a kettle, or cooking a dinner, no great temperature is required; the one thing necessary is to provide a large quantity of heat. For this purpose coal and coal gas are very cheap sources of heat, and it is generally taken for granted that electric heating must be too dear to compete against them. Yet the electric method is gradually forcing

its way into use, and in special conditions is quite displacing the other agencies.

The general idea in electric heaters, radiators, hot plates, kettles, ovens, etc., etc., is to construct them on lines similar to those previously followed, and to add a shallow chamber or jacket to hold the electric heater. Thus the electric stewpan (Fig. 59) has a very ordinary look, except for the three pins which project from its side near the bottom. These pins give electrical access to a metallic conductor fixed in a chamber or false bottom. When connected with the mains, the current which flows is sufficient to make the hidden wire very hot, and so the liquids in the pan above it are warmed up very quickly. The quantity of heat is determined by the voltage of supply and the resistance of the conductor which is subjected to the pressure. With a given voltage a greater heating is secured by having a greater current. The method is the same as that adopted in the resistance furnace, but the temperature is kept down by loss of heat which is given to the things contained in the pan. In the stewpan, for example, the hidden resistance never gets so hot as it would if the stewpan were empty, for the heat produced is withdrawn by the colder liquids above. To facilitate the transfer, the resistance lies as near the true bottom of the pan as possible.

Fig. 59.—Electric stewpan. (*Prometheus Co.*)

Electric Radiators.—Fig. 60 displays one form of radiator for warming a room, etc. It is known as

the "Electra" system, and is very efficient; *a* shows the simple metal case in which the resistance conductor is hidden. This consists of a refractory wire embedded in clay or some similar material. The outer metal case is cast round it, and serves to hold the wire, etc., rigidly together and protect the whole from violence. The case thus makes a strong radiating

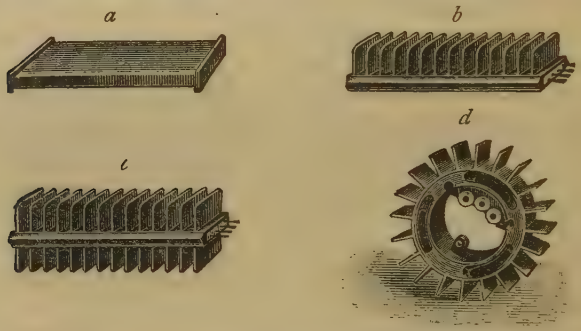


Fig. 60.—"Electra" radiator. (*Isenthal & Co.*)

a, unit with smooth surface; *b*, unit with ribs on one side; *c*, unit with ribs on both sides; *d*, circular unit with ribs.

unit. The ends of the wire are led out at one end, and can be seen in *b* and *c*. These last, as well as *d*, show the unit, with metallic ribs attached. The ribs expose a much larger surface to the air; they get rid of the heat so quickly that the temperature of the radiator cannot rise very high. This is a matter of importance, for a very hot body standing in a room acts on the organic matter in the air and decomposes it, giving rise to objectionable smells. Fig. 61 shows a radiator on its base.

Other forms of apparatus have different conductors for the resistance and different insulators to surround the conductor. Asbestos and sand are used, as

well as clay. The wire is sometimes covered with enamel, the object in all cases being the same, success depending on the mechanical strength as well as on the efficiency of the electrical adjustments. It is important

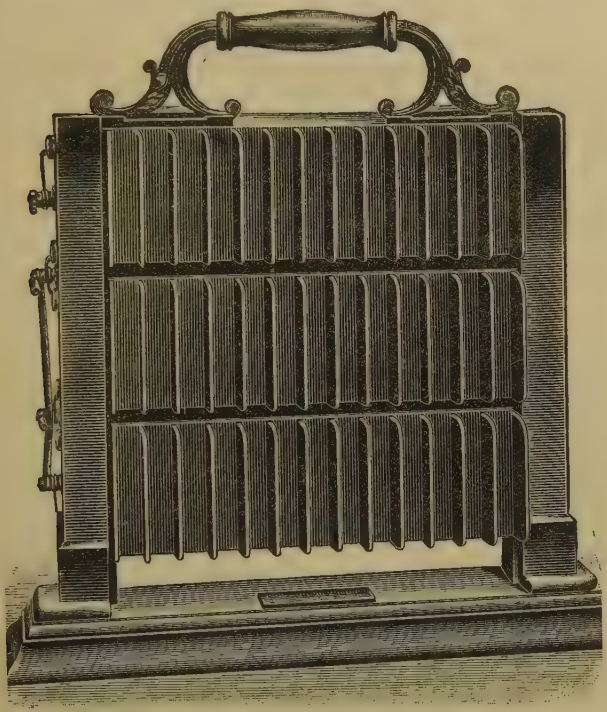


Fig. 61.—Electric radiator on base. (*Isenthal & Co.*)

that there should be no undue heating, as this might lead to fusion of the wire, or the destruction of the insulation material, or even some injury to the radiating or cooking vessel itself. A stewpan or kettle, for example, must not be joined to the mains unless

it contains water or other liquid. A margin of safety is always allowed by good makers.

The resistance conductor is arranged in various ways. Fig. 62 shows three of them; in one the wire is laid in a zigzag, in a second as a series of coils lying side by side, in a third as a flat spiral. Of these, the first and third have some advantage in being flatter than the second, for all parts of the hot wire are equally near to the surface and can thus give up their heat more easily.

The quantity and size of wire are determined by the power which the radiator heater or oven is intended to

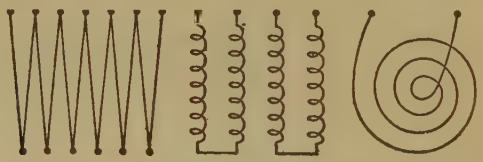


Fig. 62.—Electric resistances.

consume. Suppose, for example, that the radiator is to take a power equal to 500 watts, and to be worked on a 100-volt circuit. To get the required power the current must be 5 amperes, and the radiator resistance must be one which will not allow more than this to flow under the given pressure. It must have a resistance value of 20 ohms. If the heater is to go on a circuit working at double the pressure—that is, a 200-volt circuit—and yet take the same power as before, the current must be only half its former value—that is, not more than 2.5 amperes. To secure this the resistance inserted in the heater must be four times as great, or 80 ohms.

We shall later see that plans are adopted for regulating both the power taken and temperature attained.

Metallic Film Heater.—In some forms of heater the resistance conductor is not a wire, but takes the form of a thin metallic film deposited on a suitable non-conductor. Such a film has a very appreciable breadth, but affords the required resistance because it is so very thin.

One of the best known is the Prometheus system, which deposits non-corrodible metals on mica, and so forms strips of high resistance. The mica strips are then built up, in parallel, to form a heat producer suitable for the different powers required for different appliances. The films are protected from mechanical injury by a surrounding metal case. Fig. 63 (Plate I.) gives some idea of these services; *a* is a "film" unit intended for low-voltage circuits, *b* shows how these are applied to a stewpan.

Heating by Glow Lamps.—Glow lamps are now made to serve as "heaters," the design of the lamp being changed to suit the new purpose. Fig. 64 (Plate I.) gives an idea of one form in which four cylindrical lamps are fixed in a metallic frame, the whole forming a kind of electric stove. The electric current warms a carbon filament sealed in the vacuous glass cylinder. In this form of radiator some light is produced along with the heat, and, by making the frame of polished copper, a warm glow can be produced not so far removed from that of a bright fire.

As the primary object of these lamps is not to give light, they are designed with some differences from the ordinary glow lamp. The filament has a larger surface and does not heat beyond a cherry-red glow. One consequence of this is that the lamps last a long time. Each lamp takes about ¼ of a B.O.T. unit per hour, so that the cost per hour is about ½d. for each lamp. (This is on the assumption that the supply company

charge 2d. per unit.) The switches enable two or four lamps to be used at will.

Glow-lamp radiators are made in a great variety of frames, and make a very favourable appeal to the eye.

Comparison of Radiators.—There is a distinct difference between the ordinary resistance radiators (Figs. 61 and 63), on the one hand, and the glow-lamp radiator (Fig. 64) on the other. In the latter the filament is made very hot, but as it is in a vessel containing no air, it can get rid of its heat by radiation only. That is to say, it "radiates" its heat by the same process as that by which it radiates its light. Both heat and light pass off in straight lines through vacuum and glass, then through the air, falling on the articles in the room and warming them gently. Strictly speaking, the air is not warmed by this radiant heat; the chairs, tables, walls, people, etc., are warmed by it. Indirectly the air is warmed by *touching* these warmer objects.

In the other forms of radiator the heat is dissipated by a process known as "carrying" or convection. The outer parts of the radiator are warmed and, when touched by air particles, these becomes warmer, expand, and rise, passing away as a current of warm air. Cold particles flow in, get warmed in their turn, and give place to others. Thus this kind of radiator warms the air by a system of circulation, cold air coming to it, touching it, and becoming warmed, and then ascending.

We have therefore two kinds of heater, one which works by convection (Electra and Prometheus systems) and another which works by radiation (glow-lamp system). Of course the distinction is not so marked as this statement would imply. The glow-lamp system is not purely radiant; some of its heat is lost by con-

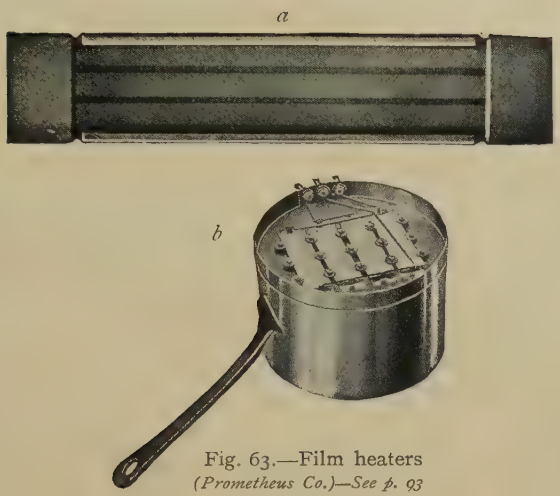


Fig. 63.—Film heaters
(Prometheus Co.)—See p. 93
a, for low voltage; *b*, stewpan

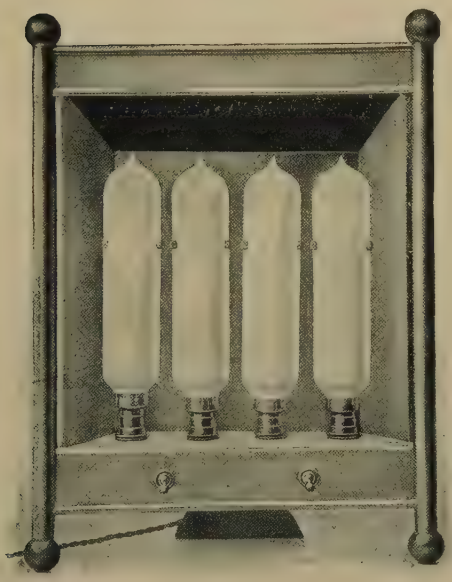


Fig. 64.—Glow-lamp radiator *(Prometheus Co.)—See p. 94*

vection. The other radiators are not purely convective in action; they lose some heat by radiation. As a matter of fact, pure convection or pure radiation is difficult to attain and very rarely desirable. But in some cases one is more valuable than the other; in other cases the relative value is reversed. On the whole, the glow-lamp method is perhaps more flexible. The glass absorbs some of the heat radiated by the filament, a process usually increased by frosting the glass. The warm glass then becomes a convector. The warming of the glass is not simply due to absorption; it is brought about in part by heat carried from the filament to the walls by means of the residual air, for exhaustion never removes all the air. An ingenious augmentation of this action has been attained by using a gas that conducts heat more readily than air can. Before the lamp is exhausted, the air is replaced by hydrogen, a much better conductor. The exhaustion then proceeds, and the residual gas is more efficient in warming the containing vessel.

By these methods, and also by arranging ventilation tubes in the framework which supports the radiating lamps, currents of air are produced which carry off a fair quantity of heat, and the loss of heat is accomplished by both the convection and radiation processes.

The practical bearing of all this is easy to follow. Where the object is to warm the *air* as readily as possible, the method of convection is best. When radiant heat is desired at definite places, the glow-lamp form is superior. In a room known to the writer the air is constantly renewed by the action of a fan placed well above the roof and driving the outer air down a shaft. In winter time the entering air is cold, and is warmed by passing over a large metallic

surface heater acting by convection. The desirable thing here is that the air should touch the warm surface as it passes, and carry or "convect" as much heat as it possibly can. A *true* radiator would not warm such a current of air, for the radiated heat would pass through it and not be absorbed.

In other cases, however, radiation is preferable. For example, a person may desire to feel the warm glow of radiant heat himself, and a glow-lamp radiator in a suitable case is the most pleasant form. The heat rays come from the lamps and strike on the feet, etc., warming them in a very agreeable way. Moreover, such a radiator can be transferred from one part of the room to another (by the help of a sufficiently flexible conductor), and the radiance secured at the spot where it is required. These illustrations will enable the reader to use his wits in deciding on an appropriate form in particular cases.

Cooking by Electricity.—Besides the radiators, kettles, stewpans, etc., which have already been mentioned, there are many appliances for cooking proper. The description of an electric oven will give an adequate idea of the working. An oven such as Fig. 65 looks quite ordinary, except for the switches and the absence of flues for hot air or gases. The heat is produced inside the oven, or rather just below the surfaces of the inside walls. Under these walls the resistances are buried in the insulating material, and are connected with the several switches, so that all or part can be joined to the mains at will. Some of the resistances are on the sides, others at the back, and others at the top. In this way a joint can be heated equally on all sides and at the top, while at discretion any particular part can be given a special heating by turning off the switches controlling the

parts which are not required. In some ovens the radiators at the top take the form of glow lamps, like those mentioned on page 93, and a flood of *radiant* heat can thus be directed on to the upper and visible part. From the cook's point of view this is an advan-

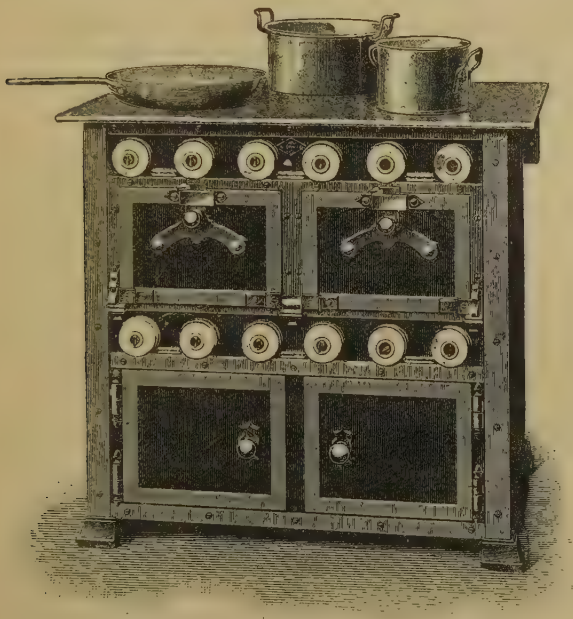


Fig. 65.—Electric oven. (*Isenthal & Co.*)

tage, as it produces the brown appearance associated with good cooking.

The top of the oven (that is, the external surface) is usually prepared as a hot plate, so that dishes, etc., can be warmed, or water boiled, and vegetables, etc., cooked. As a matter of fact, the system has

been extended to cover all the work of a cooking range.

Regulation of Temperature.—In nearly every case of heating it is desirable, and sometimes necessary, to have a method of regulating the temperature. In the electric systems this is done by altering the current, or by cutting out one or more of the conductors which get heated. For example, the glow-lamp heater of Fig. 64 is divided into two sections by switches. If both switches are on, all the four lamps glow, each giving out an equal quantity of heat. With the two switches on, therefore, the heating effect is that of four lamps. When one switch is turned off, two lamps are cut out, and the heating has been reduced by one-half. It is possible, by means of three switches, to have one, two, three, or four lamps at once.

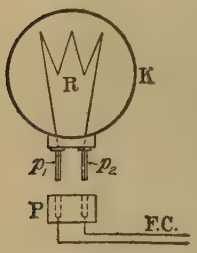


Fig. 66.—Kettle and connecting plug.

The same method of having independent resistances is used also in the case of ovens where, indeed, as many as ten switches may be provided. In smaller apparatus, however, simpler methods have to be adopted, and the regulation is accomplished by arranging the resistance in a way which allows of several combinations.

The ordinary way of joining the heater (say in a kettle) to the mains is by means of two pins. In Fig. 66, let K represent the kettle; R is the resistance underneath the bottom, being connected to pins p_1 p_2. The plug P has two metal sockets arranged to fit the two pins. The sockets are joined to the ends of the two connecting wires in the flexible cable F. C., which runs to the mains, and when the plug is pressed on

to the pins the circuit is complete, a current flows through R, and produces the heat required. In this method there is no regulation; the current is determined by the voltage of supply and the value of the resistance R.

To get regulation the heater is provided with *three* pins, connected to the resistance as shown in Fig. 67. In the Electra system the corresponding plug has three sockets, but two of them are connected together so as to be electrically one. Let us say that the

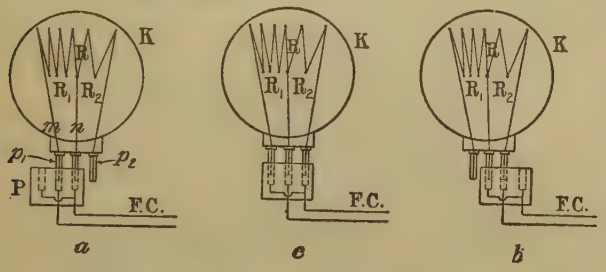


Fig. 67.—Regulating the temperature. (*Isenthal & Co.*)

middle socket is joined to the wire from the positive main, the two outer sockets are then joined to the negative main. Now if the plug be placed on the pins as in Fig. 67*a*, electricity flows through R_1 only, entering at *m* and leaving at *n*. If the plug be placed on the pins as in Fig. 67*b*, R_2 only is in circuit, and electricity flows through it only: R_2 is arranged to have a less resistance than R_1, say one-half. The current through R_2 is twice as great as previously with R_1, and the heating effect is twice as great also. By using the plug in the second way we get a greater heating effect than can be obtained by the first method. Finally, if the plug be used as in Fig. 67*c*, both R_1 and R_2 take current from the mains, and the heating

effect is now the maximum, or equal to the sum of the other two. For instance, R_1 may allow a current of 2 amperes to flow, R_2 may take 4 amperes; then in *c* the total current will be 6 amperes.

A somewhat similar method is followed in the Prometheus system. The heating resistance is provided with three pins, which divide it in the way already explained. The connecting wires from the mains are connected as in Fig. 68: one wire goes to a plug *r*, coloured red; the other wire goes to two plugs, b_1 b_2, both coloured black; electrically these two are one. The following variations are now possible:—

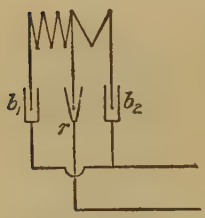


Fig. 68.—Temperature regulating plugs.

Maximum heat: *r* on middle pin; b_1 on left, b_2 on right. Current through both resistances. Total current, say 6 amperes.

Three-quarters heat: *r* on middle pin; b_1 (or b_2) on right. Current flows in smaller resistance only; say, 4 amperes.

Half heat: *r* on middle; b_1 (or b_2) on left. Current flows in larger resistance only; say 2 amperes.

Minimum heat: *r* on right, b_1 (or b_2) on left. Current in both resistances, but it is the *same* current through both, and only $1\frac{1}{3}$ ampere, because the two parts are in series, and their resistances are added together to diminish the flow. The method is simpler to use than to describe.

This method, therefore, gives a fourth degree of heating, or one more than in the former case.

Automatic Safety Devices.—We have already mentioned that, in the case of kettles, stewpans, cooking pots, etc., it is dangerous for the power to be heating them when the vessels are empty. The cool-

ing effect of the liquids is not felt, and the whole apparatus may get overheated. To prevent this, automatic contrivances are used. Fig. 69 illustrates one belonging to the Electra system. In going to the resistance the current is made to flow upwards through a pin fixed underneath at the middle of the vessel. In doing so it must pass between two discs, which are fastened together by an easily melted solder. If the pot contains no liquid, and as a consequence gets overheated, the solder between the discs is melted and allows the lower part to fall away. The figure shows the two discs separated, and also two of the three arms (one invisible) which make contact with the studs on the bottom of the kettle.

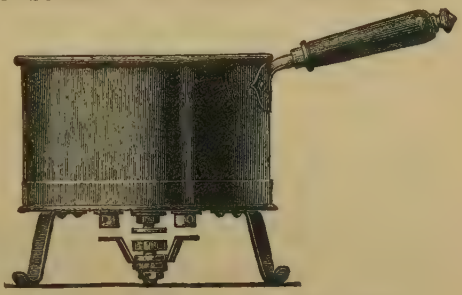


Fig. 69.—Electra automatic safety device. (*Isenthal & Co.*)

To restart the current, a new pin must be inserted.

Electric Thermometers.—A very useful development of electrical work is shown by what are known as electrical thermometers. There are two distinct electrical methods by which temperatures can be determined. They demand more care and expense than the ordinary mercury thermometers, but where very high or very low temperatures are involved they enjoy a very great success. The ordinary mercury thermometer cannot be used below − 40° F. (= −40 C.), because mercury freezes at that temperature, and as it boils about 662° F. (= 350° C.), the instrument is in danger of bursting if that tempera-

ture be reached. The two electrical methods are available at temperatures far beyond these limits; they are known as the "resistance" thermometer and the "thermopile," respectively. The latter is simple, and will be described first, using diagrams only.

Let P and R in Fig. 70 represent two thin wires of different metals, joined to the galvanometer G by suitable conductors. As soon as the temperature of the

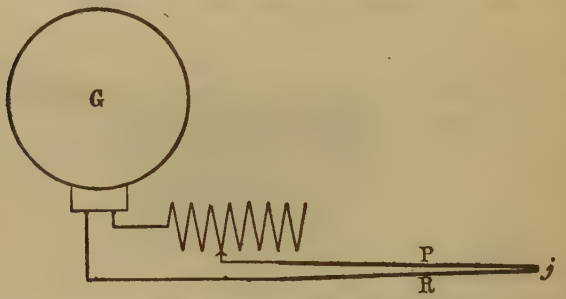


Fig. 70.—Electric thermopile for measuring temperatures.

junction j of P and R is made to differ from that of the other parts of the circuit, an electric pressure is developed, and this urges a current through the circuit. The electric pressure is small, but it can easily be measured on the galvanometer. As the value of the electric pressure depends on the temperature, the latter becomes measurable on the galvanometer. If the junction is warmed, the electric pressure acts in one direction; if it is cooled, the pressure and current are reversed. If now the indication of the galvanometer be noticed when the junction is heated to known temperatures, we can find a scale of temperatures, and then by noting the indication on the galvanometer it will be possible to say how many degrees the junction has been warmed or cooled.

In practice, therefore, the junction of the two wires is introduced into the place whose temperature is to be measured and the galvanometer indication observed. If P be made of platinum and R of an alloy of platinum and rhodium (or an alloy of platinum and iridium), the thermopile will measure temperatures as high as 2,700° F. (= 1,500° C.) and as low as 365° F. (= 220° C.).

Many details and precautions are here omitted. The general principle only is described, and that is enough for our purpose. With thin wires, such as those referred to, it is necessary to give them mechanical protection during use.

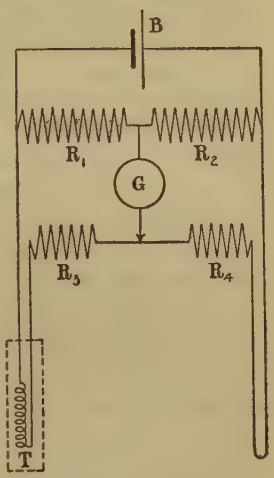


Fig. 71.—Electric thermometer.

The Resistance Thermometer.—It has been explained that every conductor offers some resistance to the passage of a current, and that the value of this resistance changes with the temperature, increasing as the temperature rises and decreasing as the temperature falls. Now the resistance of a conductor can be measured with exceedingly great accuracy, and the changes produced by heat are therefore easy to determine.

Fig. 71 shows the general arrangement. The thermometer T is a coil of platinum wire, connected to a set of resistances by long wires; T is fixed in a porcelain tube, and the latter is placed in the furnace or flue whose temperature is to be measured; B is a

battery, G galvanometer, R_1, R_2, R_3, R_4 are adjustable resistances, and one or more are altered until no current flows through the galvanometer. To measure the temperature say, of a furnace, the following operations are performed :—

First.—The resistances R_1, etc., are adjusted so that the galvanometer needle is at zero. When this is the case, a current is flowing along R_1 R_2 and another current along R_3 R_4, but none goes through the instrument, because there is a balance.

Second.—The thermometer (in its porcelain tube) is now placed in the furnace and left for a time, so that the platinum wire may acquire the same temperature as the furnace. As it warms up its resistance alters and the balance is upset; the galvanometer needle moves.

Third.—The resistance R_2 is now increased to restore the balance, that is, till the galvanometer needle is brought back to zero.

The change which has to be made in R_2 is a measure of the temperature in the thermometer wire T, and after the instrument has been calibrated on known temperatures it is easy to say what the change in R_2 actually means. This is an exceedingly accurate way of measuring temperatures. It is possible to detect the thousandth or even the ten-thousandth part of a degree. In the same way very low temperatures can be measured. If, for example, the thermometer T be placed in liquid or solid air, its resistance is very much diminished, and R_2 must be reduced till a balance is again obtained. The temperature is again found from the change in R_2.

CHAPTER V

ELECTRIC LIGHTING

Arc Lamps.—In the section on furnaces some account was given of an electric "arc" (*see* page 85). The arc lamps employed for furnace purposes are nearly always of the "hand-feed" type—that is, as the carbons are consumed, they are fed forward by a rack worked by the hand of the operator, a method which suffices for heating and similar purposes, where abrupt transitions are of no great moment. By careful management a hand-feed lamp can be employed for lighting, and is constantly used for projecting lanterns and for searchlights. But for an ordinary arc lamp hand feeding is impossible; the expense of the attendant alone would be prohibitive. Some automatic method must be adopted, and the mechanism must be such as will maintain a steady light. Let us see what is required to do this. We shall first speak of what is called an "open" arc, and deal with "closed" and "flame" arcs afterwards.

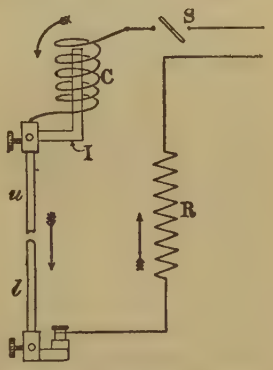


Fig. 72.—Diagram of arc lamp

Fig. 72 is a sketch of the effective part of an "open" arc. There are two carbon rods, *u* the upper and *l* the lower. In general, the upper carbon is

connected to the positive end of the dynamo or battery, so that positive electricity flows downwards through the arc.

The carbons are generally touching when the lamp is not in use, and the whole of it offers very little resistance. Consequently, an enormous current begins to flow as soon as the switch s is turned on; but its value is at once reduced because the carbons are separated, thus introducing the resistance of a column of vapour into the circuit. For each lamp there is a particular length of arc which is best for steady working, and we will assume this distance to be struck. It varies from $\frac{3}{32}$ to $\frac{1}{8}$ of an inch.

The arc does not preserve a constant length. The carbons consume away, the positive (upper) twice as quickly as the negative. Hence they must be fed forward to make up for consumption and keep the working arc as it was. If this "feeding" is not carried out, or if it is too slow, the arc will presently get too long for the voltage, so that the battery cannot maintain the current across it; the arc will then go out, and cannot be renewed except by bringing the carbons together.

There are thus two chief requirements of an automatic arc lamp: first, it must strike an arc of the right length; secondly, it must feed the carbons forward as fast as they are consumed, so as to keep the arc of constant length. Generally speaking, the carbons consume away at about $\frac{3}{4}$ inch per hour.

The first of these necessities is managed by an electromagnet, which lifts the upper carbon as soon as current flows. Fig. 72 shows the arrangement. The upper carbon is attached to an iron holder 1, which acts also as a core to the coil c. Any current flowing through c is led to 1, and then through the carbons to a second terminal. The course is shown by small

arrows. A resistance coil R is in series with the lamp, and acts as a steadying coil, tending to make any changes of current and light less abrupt.

When the switch S is closed, the coil C magnetises I and sucks it up, thus striking the arc. When the arc is about the right length, the upward magnetic pull just balances the downward pull due to the weight, and the carbon floats. As the carbons wear away the arc gets too long, the current and its magnetic pull diminish, and the core, etc., fall a little. For a time, therefore, the arc is kept about the right length. After a while, however, as the carbons lose weight, the adjustments are no longer sufficient, and the series coil has to be supplemented by another, called a shunt coil. Fig. 73 shows these arranged diagrammatically, the lamp being one of the simplest.

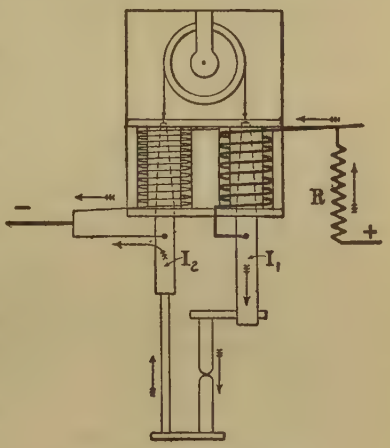


Fig. 73.—Pilsen arc lamp.

Each carbon is attached to an iron core I_1 I_2, the upper ends of which are joined by a thread which passes over a pulley. The upper carbon and its iron core are made slightly heavier than the other, and this excess of weight makes the one descend and the other ascend until the carbons meet. When the lamp is switched on, electricity flows through both coils, and

both cores are drawn up. But the current through the thick series coil is very strong at first, and the pull on the upper carbon is, therefore, the greater. This difference in pull causes the upper carbon to be raised more than the lower, and the arc is struck. As the arc forms it introduces a much higher resistance in the series circuit and its current is largely reduced, taking a normal value, say of 5 or 7 amperes. At this point a balance is obtained between the weight of the carbons and the pulls due to the series and shunt coils. When the carbons have worn away a bit and the arc has become too long, the series current is reduced, the shunt current is increased. Hence the lower carbon is raised more than the upper, and the arc is restored to its full length once more. None of the devices for keeping an arc lamp regular is sufficient of itself. An imperceptible slow feed is the desirable thing, whereas some slight jerkiness is unavoidable in the mechanism. Moreover, the electric changes may be very abrupt and produce sudden changes in light. To steady the current the mechanism must be reinforced by a regulating resistance R, placed in series with the lamp. The result of this is to reduce the proportionate effect of any change in the arc. If there be no resistance added, and the arc changes its length and resistance say by 2 per cent., then the current will change in nearly the same proportion and the light vary very much more. But if a series resistance is used, a 2 per cent. change of resistance in the arc will be less than 2 per cent. of the whole resistance, and the change in current and light will be much diminished. About 7 to 10 volts are generally lost in this resistance.

Johnson and Phillips Arc Lamp.—This is shown in diagrammatic form in Fig. 74. The series coil, wound with thick wire, and the shunt coil, with thin,

are easily recognised. The cores form a see-saw, and a link carries their motion to the system for controlling the arc.

The upper carbon holder *u* has a rack on one side, gearing into a small toothed wheel *w*. On the same spindle as *w*, and therefore turning with it, is a brake wheel BW. Besides these, the same spindle supports a metallic sector *s*, but is not fixed to it. The sector can, therefore, turn independently on the spindle, unless it is temporarily linked with it by a band brake *b*, which passes round the brake wheel BW. When *b* is tightened it binds together the sector and the brake wheel, because its ends are fastened to a point on the sector and to one end of a lever linked with the see-saw.

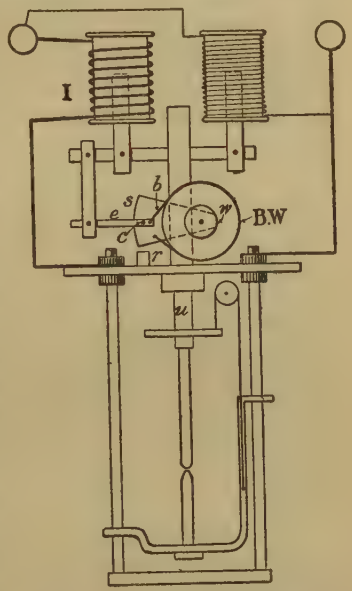


Fig. 74.—Johnson and Phillips arc lamp.

When the lamp is not in action the brake wheel is quite free, because the sector has fallen and rests on the little rest *r*. The weight of the upper carbon and its holder then causes the carbons to come together.

When the lamp is switched on, a strong current flows through the series coil and I is lifted up. This raises the link and the lever *e*, turning the latter also

on its centre *c*, and bringing the ends of the brake band together. This tightens the grip of the band on the brake wheel and locks the sector, brake wheel, and upper carbon together. The whole of them are raised about $\frac{1}{20}$ of an inch. As the lower carbon hangs by a cord connected with the upper carbon, it falls as much as the upper carbon is raised.

It is in this way that the arc is struck. In brief, the pull of the series coil on its core raises the sector and upper carbon holder by locking the sector and brake wheel, while the link lifts them up.

The feeding of the carbons so as to make up for consumption follows a reverse order. As the arc lengthens the resistance of the series circuit increases and its current falls. Consequently the pull diminishes, while at the same time the shunt current increases. The see-saw is now reversed; the left side goes down somewhat. The effect is to separate the ends of the brake band and to set free the brake wheel. When this occurs the weight of the upper carbon at once drives the brake wheel, etc., round, thus allowing the two carbons to come a little nearer together and restoring the arc to its original length.

These lamps, like many others, are provided with an automatic apparatus for cutting out the lamp if anything goes wrong with it.

Voltage Required for Arc Lamps.—Arc lamps of the type described require about 38 to 40 volts to work them properly, but to this must be added about 10 volts intended to be spent on the regulating resistance in series with the lamp. Hence, we may say that 45 to 50 volts ought to be provided for the lamps. If the current be 10 amperes, the power spent is about 500 watts. How much light is obtained from the expenditure of this power varies with the kind of lamp.

Illumination by Arc Light—Difference between Positive and Negative Carbon.—When an arc lamp is working well there is a marked difference between the positive and the negative carbon. The positive forms a "crater" at its end, the negative becomes more or less pointed. The ends of the carbons in Fig. 76*a* (p. 117) give a rough idea of the appearance. The crater and adjacent parts of the positive carbon are much more luminous than the end of the negative carbon, and indeed they form the source of most of the light given by an arc lamp. The arc proper—that is, the incandescent vapour—gives very little light. In consequence the upper carbon is nearly always made the positive, so that the crater formed at its end may throw the light downwards.

For good results it is necessary that the crater should be a regular one, and formed symmetrically with respect to the carbon. To secure this, and to prevent it from forming at the side, the upper carbon is often cored, that is, it has a kind of backbone of softer carbon running along its whole length. When in action, this core consumes away more readily than the outer parts, and therefore helps to form a regular cavity.

The fact that the negative carbon is just below the luminous crater prevents the space underneath and immediately round the lamp from being illuminated, and there is a very irregular distribution of the light. Very little or none travels upwards from the arc; there is but little in a horizontal or vertical line; the greatest value is found in a line about half way between the two, say 50° below the horizontal. The cause of the inequality is seen to lie in the crater-like form of the positive carbon and the obscuring effect of the negative below.

Inverted Arc Lamp.—In certain offices, like drawing offices, it is very desirable that the illumination should be uniform and free from shadows. This has been secured by inverting arc lamps, and thus causing the light from the crater to flow upwards. It then falls on a whitewashed board, or on a white ceiling, and is thus reflected in all directions towards the desks, tables, etc. This has proved a very successful plan in special cases.

Enclosed Arcs.—It has already been stated that the carbons of an ordinary arc lamp consume away at the rate of nearly one inch per hour, which means that they will last about 10 to 16 hours if of ordinary length. Part of the consumption arises from the way in which the current transports white-hot particles from one side to the other; but another part arises from the direct action of the air on the white-hot carbon, burning it into carbonic acid in the ordinary sense of combustion. If it were possible to prevent the free entry of the air into the globe surrounding the arc the carbons would probably last much longer. This is found to be the case in enclosed arc lamps where the carbons are surrounded by a glass envelope or globe which is nearly air-tight. Fig. 75 gives some idea of what is meant. The regulating mechanism is omitted; it need not be essentially different from that used for open arcs, though some features are magnified. The enclosing vessel is a glass cylinder, which fits nearly gas-tight top and bottom.

Besides the fact that the carbons last much longer, there are several other points worth mentioning. First, the arc is generally much longer than in the open type; secondly, the carbons no longer assume special shapes—they both take the form shown in the figure; thirdly, in consequence of the longer arc possible, the

closed arc can be worked at a higher voltage, some arcs running at 120 or more volts; fourthly, as there is no cavity and each carbon gives some light, and as the arc itself gives a larger proportion than before, the distribution of the light is different. In Fig. 75 the upper carbon *u* passes nearly gas-tight through the top of the glass vessel *v*. The oxygen of the air enclosed in this vessel is soon consumed when the arc is started, and further *burning* is practically stopped, though the arc still continues. The subsequent consumption is due to electric transport and disintegration.

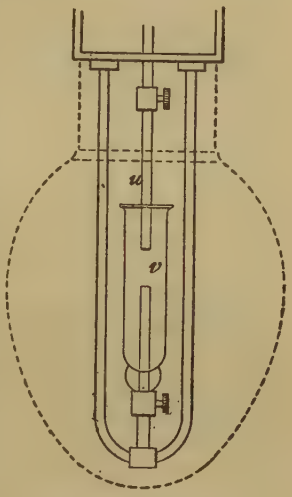


Fig. 75.—Enclosed arc lamp.

Flame Arcs.—This is the latest type of arc lamp. It differs from the others in using special carbons. During the manufacture these are impregnated with a substance known as fluorspar, its chemical name being calcium fluoride. About 15 per cent. of this is ground up with the carbon when the rods are being moulded. Several other differences in the lamp flow out of this. When the carbons are burning the mineral is vaporised and to some degree decomposed. Consequently a large amount of solid matter is thrown off from the arc, and tends to collect on the neighbouring parts of the lamp. It is this mineral matter, glowing intensely in the heat of the arc as it escapes, that causes the fine glow of this lamp. The globe looks like a flame

of fire. From the side of illumination the arc is excellent, but the solid matter given off tends to corrode the mechanism of the lamp. This tendency is corrected by separating the arc and its mechanism more effectively than usual. The carbons are longer and the mechanism is more carefully boxed in. Moreover, the carbons are not placed vertically, one over the other. They fall down inclined slides and touch at their lower ends, as suggested in Fig. 76*d* (p. 117). Here they pass through a small earthen inverted cup, which serves the purpose of checking the ascent of solid matter and of reflecting the light downwards. Its reflecting value remains good because the fumes condensed on it form a fine white deposit.

The regulating mechanism in the case above includes a series and a shunt coil, with one or two extra attachments.

Efficiency of Arc Lamps.—An important question arises as to the relative efficiency of the three types of arc lamps—the open, enclosed, and flame arcs. By efficiency is meant the quantity of light obtained for a given power expended. The best experiments show that the efficiency runs in the following order:—

Flame arc, 5 candles per watt expended.
Open arc, 2 candles per watt expended.
Enclosed arc, $\frac{2}{3}$ candle per watt expended.

It is the usual practice to state these results in the converse fashion, quoting the number of watts which have to be spent to obtain each candle. So regarded, the figures become:—

Flame arc, 0·2 watt per candle.
Open arc 0·5 watt per candle.
Enclosed arc, 1·5 watt per candle.

The differences in the light produced can be ex-

plained fairly well. The most luminous part of an ordinary arc, as we have seen, is the positive crater—most of the light comes from that part of the arc. But this part is not formed in the enclosed arc; the carbons burn flat, and though they get very hot, they do not equal the intensity and surface of the crater. The longer arc makes up for this to some extent. In the flame arc a fairly large body of vapour is heated by the arc to an intense golden white heat, and it is this which causes the higher return of light for power spent.

The reader may be inclined to think that the decidedly lower efficiency of the enclosed arc would cause it to be neglected for practical work. It can, however, claim two advantages. It gives a more efficient photographic light than the other arcs; strong in blue, violet, and ultra-violet. Further, it can be run at higher voltage, even as high as 150 volts or more. This enables it to work on supply circuits at 200 volts without undue waste. The other types of arc work at lower voltage—open arcs at about 48 to 50 and the flame arcs at not much more. Consequently, on higher-voltage circuits the last two must either be run in series or else the power due to the excess volts must be frittered away in a resistance coil.

Alternate Current Arc Lamps.—In these the current fluctuates in direction, the frequency being generally about 50 or 60 per second; in other words, the current passes through a cycle of change in about one-fiftieth of a second.

Many of the lamps used for direct current will work with alternate current if the iron cores of the electromagnets are built up of thin wire or thin sheet. Of course, each carbon is alternately positive and negative, so that they cannot show the difference found in the ordinary arc. They burn to the same shape and

they consume away at an equal rate. Another difference arises from the foregoing: they give as much light above as below, because the two carbons are alike. Each lamp requires only 38 to 42 volts.

The alternate-current arc is not quite so satisfactory as that produced by a direct current. It emits a humming noise, due to the frequent changes in direction. There is also some degree of fluctuation in the quantity of light, for each cycle of current involves a moment at which the current has ceased to flow in one way and has not yet begun in the reverse. Momentarily there is no current, and the white-hot carbons cool slightly before the current rises again. The light thus undergoes a rise and fall in intensity every time the current reverses, though fortunately the variation is not as a rule observable, because the recovery is so rapid.

Distribution of Light from Arc Lamps.—The curves in Fig. 76 show the distribution of light from different arcs. Distances from the centre to any point on a curve show the relative luminosity in that direction. The open arc lamp gives a very irregular illumination, little light above the arc, none directly below, a maximum about 40° below the horizontal (Fig. 76*a*). In an enclosed arc the distribution is changed as shown in Fig. 76*b*. More light is found above the arc, and very much more than in the open arc at 50°, 60°, 70°, and 80° below the horizontal. The general distribution is much better in the enclosed than in the open arc, although the total amount of light is less for the same power. In the flame arc the distribution (Fig. 76*d*) is still more general, partly because the light is reflected downwards and partly because the arc seems to fill the opal globe. It is pre-eminently adapted for outdoor illumination. The alternate arc gives a peculiar form of distribution curve (Fig. 76*c*). It is to be

understood that the values of light shown in these curves apply all round the arcs.

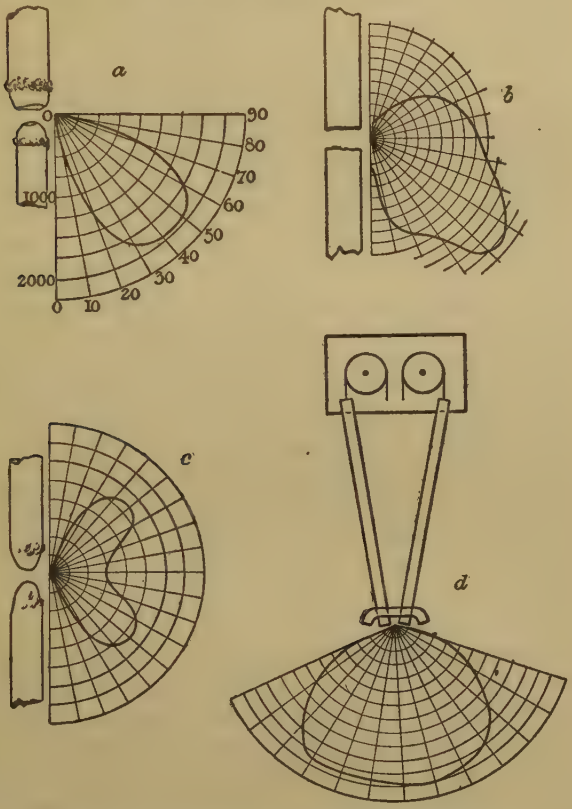


Fig. 76.—Distribution of light from different arcs.
a, open arc; *b*, enclosed arc; *c*, alternating arc; *d*, flame arc.

Incandescent or Glow Lamps.—The lamp now commonly used for domestic lighting purposes consists

of a thin conductor of high resistance raised to a high temperature by an electric current of appropriate strength. At the present time there are three kinds of these lamps, namely: (1) The carbon lamp; (2) the tantalum lamp; (3) the osram lamp.

These differ in the material used for the working filament. The first uses a filament of carbon, the second a filament of the metal tantalum, the third a filament of the metal tungsten. In brief, the lamps are made of carbon, tantalum, and tungsten wires. In other respects, apart from efficiency, the lamps are much alike. In each case the filament is enclosed in a vacuous glass globe, and provided with a suitable cap by which connection can be made between the ends of the filament and the wires which carry the current to and from the dynamo, when these are joined to the contacts in a suitable lamp-holder socket. The important feature of each lamp are the filaments, and we must say a few words about the manufacture of these.

Carbon Lamp.—The carbon filament is made by taking pure, clean cotton wool and dissolving it in a strong solution of a substance known as zinc chloride. The liquid thus formed is like a very stiff glycerine or thick treacle, moving with great slowness.

Squirting the Solution.—The solution of cotton wool is squirted through a small hole, and emerges as a fine thread of liquid. It falls immediately into a vessel containing alcohol, in which the zinc chloride is soluble while the cotton is not. Consequently the zinc chloride diffuses out into the liquid, and leaves the cotton still falling as a fine round filament. But it is no longer a mass of fibres; it is like a thread of flexible glass, and as such falls to the bottom of the vessel. After being completely washed in water to remove all traces of the zinc chloride, it is wound on

a "former" and carbonised in a furnace. The "former" determines the final shape of the filament—either a simple bend or a loop with one or more turns. To carbonise, many "formers" with their filaments are placed in an iron box, being packed round with powdered charcoal to prevent the furnace gases from acting on the threads. When packed thus, and their lids securely luted on, several boxes are placed in a good furnace and subjected to a long and intense heating. The temperature is raised gradually, and finally kept at the highest value for some time. On cooling, the boxes are opened and the "formers" removed. The cotton filaments have decomposed, the gaseous elements in the cotton have been removed, and carbon only is left. The filament is a wire of pure carbon, very black and elastic. It is not yet fit for work in a lamp. Some parts are weaker than others; if heated by a current these weak parts get hotter than the rest and soon give way. To make it uniform the filament is "flashed." This means that it is placed in a chamber containing a little benzene vapour (or coal gas) mixed with some air, and while there subjected to a current which makes it glow. Carbon from the benzene vapour is deposited on the glowing filament, but the weak parts, being the hottest, get more than the others. The result is that the filament is made uniform and takes a uniform temperature. The deposited carbon is more resistant than the other. The flashing is continued till the filament has been reduced to the right conditions to suit the batch of lamps being made, and is then trimmed in length. Its ends are securely connected to platinum wires by a deposit of hard carbon at the joints, and these then sealed in through the neck of a glass bulb. The end of this is then connected to a special pump giving a very good

vacuum and the air exhausted as completely as possible. As soon as this is accomplished a gas blowpipe flame is directed on the point and the bulb sealed off.

The ends of the wires are soldered to two brass segments insulated in the end of a cap, which is now cemented to the lamp, and is then ready for use. In recent years platinum has become so dear that only very short lengths are employed to seal the connecting wires through the glass. Fig. 77 gives a good idea of a glow lamp.

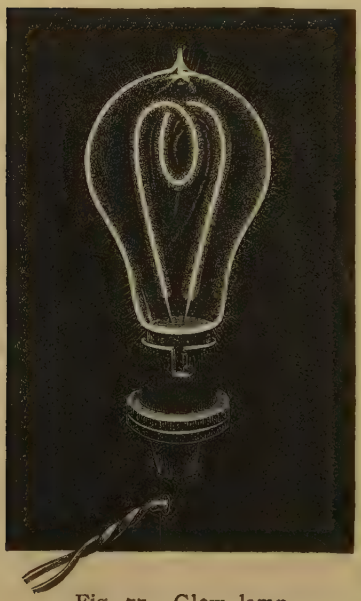


Fig. 77.—Glow lamp.

Carbon lamps are usually made to give 8, 16, 32, or 50 candle-power. But each of these is made in different ways—one to suit low voltage, another to suit high voltage, and others to suit intermediate voltages. Thus we have 16 candle-power 100-volt lamps, 16 candle-power 200-volt, 16 candle-power 240-volt. The real meaning of these will be described after dealing with tantalum and osram lamps.

Tantalum Lamps.—In these the filament is made of a metal named tantalum, a whitish, bright-looking metal obtained from a mineral named tantalite. Its

melting point is very high, so that it can be raised to a high temperature without fear of fusion. The temperature is higher than that of the carbon lamp.

The appearance of the lamp is seen in Fig. 78, where the lower part of the bulb is frosted. It will be observed that the filament is in the form of a long zigzag, the length being much greater than that of a carbon filament. It is also much thinner. These changes in dimensions are rendered necessary because of the greater inherent conductivity of the metal. If it were made of the same dimensions as the carbon filament for a given voltage, much too strong a current would flow; its candle-power would be enormous, but its life would be too short. By making it thinner and choosing its length aright, a tantalum filament for 100 volts is made to have a resistance about twice as great as that of a carbon filament. When it is placed in its holder, therefore, it allows only half the current to flow, and yet it is heated to a higher degree of incandescence than carbon. It gives about the same quantity of light, and thus makes a more efficient lamp.

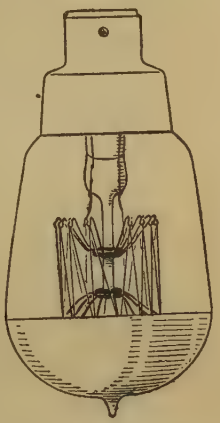


Fig. 78.—Tantalum lamp.

The tantalum filament is not yet made for very high voltage.

Osram Lamps.—These lamps are now practically made of the metal known as tungsten. The origin of the name is peculiar. Some years ago glow lamps were made of a very expensive metal called osmium, a metal allied with platinum in its chemical nature.

Osmium lamps were very efficient, giving a good light for very little power; the chief disadvantages were the high price and the fact that the lamp could not be made suitable for high-voltage circuits (100 or 200 volts). After some time a mixture or alloy of osmium and wolfram (the latter being the German name for tungsten) was used for the filament, and such lamps were known as *osram* lamps. The cost of the osmium has, however, excluded it, and at the present time the osram filament is practically made of tungsten (wolfram) alone. Fig. 79 indicates its general appearance.

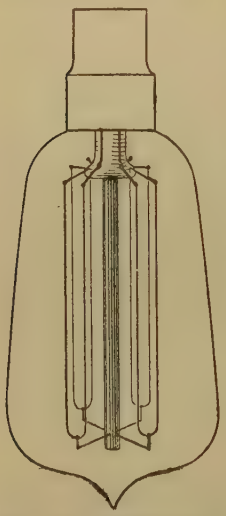


Fig. 79.—Osram lamp.

The main points of the osram lamp are similar to those of the tantalum. Having a much lower resistance than carbon, it is made very thin in order to provide the necessary resistance. Its length also is great—greater even than in the tantalum lamp. It can be safely heated to a higher degree than either carbon or tantalum, and has a very good life. Its efficiency is greater than the others.

We shall discuss the properties of these different lamps, but must first explain the meaning of several phrases which are in constant use, such as candle-power, efficiency, life, etc.

What is Meant by Candle-Power—How to Make a Simple Photometer.—The standard of light in use in England is that of a special sperm candle, weighing six to the pound and burning at the rate of

120 grains of sperm per hour, or 2 grains per minute. When it is said that an electric lamp is a 16 candle-power lamp, it is implied that the lamp radiates as much light as do 16 of these standard candles. There are various ways of judging of the candle-power, and if the judgment is one that makes a claim for accuracy a great deal of care and skill is required in making the arrangements. But for ordinary purposes the apparatus described here will suffice, and has the advantage that it can be made by the reader.

Fig. 80 is a diagram of the simplest photometer: L is an electric glow lamp, C is a candle (an ordinary

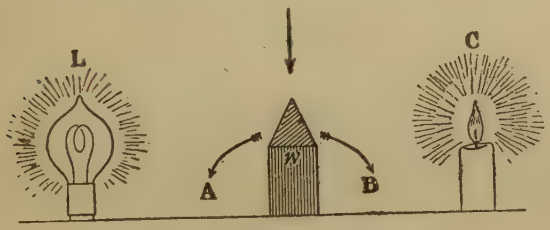


Fig. 80.—Simple photometer.

paraffin candle about six to the pound will do), and *w* is a wedge whose sloping surfaces serve as the photometer. The wedge may be made of white wood or paper. The side A is illuminated by the lamp L, the side B is illuminated by the candle C, and in general one of them will look brighter than the other. But by moving the wedge nearer to the candle a spot can be found at which the observer, looking down on the two surfaces of the wedge along the line of the arrow, cannot see any difference between them in respect of brightness. They are then equally illuminated; that is to say, the candle light falling on B is equal in intensity to the electric light falling on A.

From this fact, and the relative distances between the screen and the two lights, the candle-power of the electric light is calculated. Thus in a particular case the screen showed equal illumination when 80 inches from L and 20 inches from C. These distances are as 4 to 1. But light falls off according to the square of the distance, and we must square the figures before taking the proportion. The squares of 80 and 20 are 6,400 and 400, or 16 to 1. Therefore the lamp L is giving 16 times as much light as the candle C, because it gives equal illumination at 4 times the distance. The candle-power of the lamp is therefore 16.

If the single candle could be replaced by 16, the wedge would be equally illuminated when placed half way between them and the electric lamp. The wedge here employed, along with a scale to indicate distances from the two sources of light, is called a photometer or "light measurer." It is one of many different forms, and probably the simplest. The wedge ought to have a sharp angle, say about 60° to 70°, and the edge ought to be as sharp as convenient. It is important in using this or any other photometer to exclude all other lights except the two that are being compared.

Study of a 16 Candle-Power Lamp.—Certain points in the behaviour of a lamp will be more easily described if a particular lamp be chosen as a specimen. Taking, therefore, a 16 candle-power carbon lamp as a sample, we notice that it is marked 100-16. This means that it is intended to be worked at a pressure of 100 volts, and that it ought then to give a light of 16 candles. As a matter of fact, it will give 16 candles at this pressure only. If the pressure be increased, the lamp gives much more than 16 candles.

If the pressure be reduced the lamp gives less than 16 candles. In each case the luminous efficiency changes tremendously.

Consider the following table, which shows the candle-power of a 16 candle-power carbon lamp when run at lower and higher voltages.

100-VOLT CARBON FILAMENT LAMP RUN AT VARIOUS VOLTAGES.

Volts pressure.	Candle-power.	Percentage change.	
		In volts.	In candles.
100	16	—	—
97	12.7	3% fall	20% fall
105	20	5% rise	25% rise

This table brings before us the following points:—

1. The 16 candle-power lamp can give either a greater or smaller quantity of light, according to the pressure put on it, with a consequent change in current flowing through it.
2. The change in candle-power is much greater than the change in voltage. Three per cent. *fall* in volts produces 20 per cent. *fall* in light; 5 per cent. *rise* in volts produces 25 per cent. *rise* in light.

An important question therefore arises, namely, Why is this lamp not used on a circuit giving 105 volts pressure, where it would yield 20 candles instead of 16?

The answer to this may be deferred till we have explained another point. Let us consider the power spent on each lamp at the different voltages, and then find how much power is spent per candle.

Efficiency of Lamp.

POWER SPENT ON 16 CANDLE-POWER LAMP AT VARIOUS VOLTAGES.

Pressure in volts.	Current in amperes.	Power in watts.	Candle-power.	No. of watts for one candle.
100	0.64	64.0	16.0	4.0
97	0.615	59.8	12.7	4.7
105	0.662	69.5	20.0	3.47

From this table we gather further important information. Not only does a higher voltage mean more light; it means that, candle for candle, we get it at less cost.

Let us suppose we want a total illumination of 100 candles, and that we are to get it from lamps of this kind. If we ran them at the different voltages given the power required would be 400 watts at 100 volts, 470 watts at 97 volts, 347 watts at 105 volts. Clearly the cost for power will be much less at 105 volts than at either of the other two. The return in light for power used is greater, or, as it is generally expressed, the *efficiency* is greater.

Efficiency and Life.—The efficiency of a lamp is stated when we know how many watts are required for each candle obtained. With carbon lamps the average efficiency is about 4 watts per candle. To put the matter in a reverse way, we may say that we get $\frac{1}{4}$ candle for each watt in the power spent on the lamp.

But the foregoing tables show that this efficiency can be increased by raising the volts. Why, then, is this not done? We save one-sixth of the cost for power by raising the volts 5 per cent. In face of such obvious economy these lamps would always be run at

higher pressure than that marked if it were not that such over-running shortens their life. The cost for power would diminish, but the cost of lamps would increase, for each lamp would last a shorter time. Moreover, when overrun, the glass blackens because of an internal coating of vaporised carbon, and this absorbs a good deal of the light produced. Hence it is important to work the lamps at the pressure marked by the maker.

Now compare two lamps, one of which is marked 100-16, the other 200-16. Both are to give 16 candles, but the first is for 100-volt circuits, the second for 200-volt circuits. What is the difference between them?

The 200-volt lamp will have a filament longer and thinner than the other. This is used to produce a higher resistance; indeed, it must have four times the resistance of the first. The consequences of this are very interesting. Having four times the resistance, it takes only half the current at 200 volts that the other does at 100 volts. Hence it works at twice the pressure and takes half the current, thus absorbing the *same power in watts.*

Comparison of Carbon, Tantalum and Osram Lamps.—We have seen that these lamps are very similar. They differ only in the material used for the filament. All three kinds are more efficient when worked at higher voltages than usual, but at the same time their life shortens. They are therefore so made that when run at the voltage marked on them they will have a useful life of about 1,000 working hours.

Under these conditions the osram lamps are the most efficient, the tantalums being intermediate between these and the carbon type. The following figures show

the difference. One candle is obtained at the following expenditure of power :—

In a carbon lamp, 4 watts.
In a tantalum lamp, 1·7 watt.
In an osram lamp, 1·2 watt.

The osram is 3·3 times as efficient as the carbon and the tantalum 2·3 times. This increased efficiency arises from the higher temperature at which the metal filament lamps can be run. The temperatures are roughly estimated to be :—

Carbon filament ...	3,420° F.	1,900° C.
Tantalum	3,700° F.	2,050° C.
Osram	4,110° F.	2,300° C.

At the higher temperatures a larger proportion of the energy spent is changed to light and a smaller proportion into heat.

This is a convenient place to say that all efforts to get light are crudely unscientific. In the case of these lamps not more than 6 to 8 per cent. of the energy is changed to light—the rest is spent in producing heat. Now, as a rule, this heat is not wanted. It is produced because we do not know how to get light from a body except by heating it. The method is crude because it is so extravagant. Light and heat consist of similar vibrations in the ether; they differ only in the rapidity of the vibrations. When a body is warmed it sets up ethereal vibrations. Up to a certain stage these are unable to act on our eyes, and we can see no light, although we can feel the radiant heat. Up to this point the luminous efficiency is zero: as far as light is concerned we get no return for energy expended.

As the body is warmed to a higher temperature we begin to get a little light. First we get 1 per cent.,

then 2, and so on, an increasing proportion of light with increasing temperature. But, however hot the body may be, it always gives off most of the energy as heat. We always get more heat than light. To see the point more fully, let us compare this case with an organ. Let us suppose that a musician wants to produce the vibrations given by the organ pipes of the shorter length (more rapid vibrations), and that to do this he has to begin sounding the longest and go on ascending till he reaches the shorter, keeping the longest ones working all the time. How wasteful this seems; yet it is comparable with our ways of producing light, whether by electricity, or gas, or oil, or candles. As a matter of fact, an electric lamp converts a larger proportion of energy into light than any of the other methods.

It is interesting in this connection to notice that the glow-worm and fire-fly are more skilful than we are. The light they produce is not very great in quantity, but it is obtained without wasting energy on heat. All the work they put into the task is converted into light. This is far superior to the 4 per cent. we obtain with gas, or the 6 per cent. by electrical aid. It indicates the possibility that future discoveries may give us light by a more economical process, but does not suggest a method. The most promising is by some special form of vacuum tube, but the difficulties are as yet very great.

Will Carbon Lamps be Replaced by Osram and Tantalum?—As tantalum and osram lamps give light for less power—that is, reduce the electric light bill—they promise to replace carbon lamps. The question will be finally decided by taking account of the *total* cost of lighting and the convenience of the size of the lamps. For domestic lighting 8 or 16 candle-power

lamps are most wanted, but the metallic lamps are not made under 16 to 32 candle-power, and even these are for circuits working at 100 or 120 volts. For circuits running at 200 or 250 volts the smallest candle-power lamp is 40 to 50 candles for osram or tantalum and as low as 8 candles for carbon. The cost of the metal lamps is also much greater. A carbon lamp costs ninepence, tantalum two shillings and sixpence, osram lamps about four shillings. We can get a good idea of economy from the following table, in which the cost of power and cost of lamps are added together. It is supposed that the charge for energy is threepence per Board of Trade unit, and that each of the 100 lamps gives 16 candles; that is, the total charge is for *equal* quantities of light.

TOTAL COST OF LIGHTING BY GLOW LAMPS.

	Carbon.	Tantalum.	Osram.
Cost of 100 lamps ...	£3 15 0	£12 10 0	£20 0 0
Cost of power for 1,000 hours at 3d.	80 0 0	34 0 0	24 0 0
Total cost	£83 15 0	£46 10 0	£44 0 0

These figures show such an advantage for the metal lamps that there is sure to be an increasing demand for them, and carbon lamps will lose the supremacy which they formerly enjoyed. It is to be noted that the total cost would be still more in favour of the metal lamps if the charge for power were fourpence per unit. The advantage is generally lost because more light is expected from metal lamps.

CHAPTER VI

ELECTROPLATING—ELECTROTYPING—ELECTROLYSIS

SOMETHING has been said already about electroplating. On page 54 there is a short account of the way in which an electric current deposits silver, and it is there stated that the weight of silver deposited can be used to measure the quantity of electricity. Other metals can be deposited in much the same way. We have now to explore this part of the subject more fully. It is one of the most interesting of the electric topics, involving very important practical processes and also profound theoretical conclusions.

To begin with, electroplating always requires the use of special liquids: it is impossible with solids. The liquids employed in commercial electroplating are always solutions of salts in water, and we must explain what these are.

There are many simple liquids, such as water, alcohol, acetic acid, olive oil, paraffin oil, petroleum, sulphuric acid (known also as oil of vitriol), nitric acid (known also as aqua fortis), and hydrochloric acid (known also as spirits of salts). As long as these liquids are *pure,* they behave as non-conductors or insulators, and as such we have little concern with them, though it seems a little strange to think of water as a non-conductor. Emphasis must be laid on the fact that it is only when *pure* that it can be classed with the insulators.

In this respect water is not unlike many other liquids. Like them, however, it becomes impure by

dissolving other substances, and in its ability to do this water far transcends all other liquids. The moment it has begun to act as a solvent water becomes a conductor, though its conductivity is of a special kind. Electricity, like other things, can be transferred in several ways. Water, for example, is transferred to our houses through conducting pipes: this is conduction similar to that of electricity in metals. Again, in some remote parts of the country water is carried in carts to the places where it is wanted. This is similar to the conduction or convection (which means carrying) of electricity in water solutions, for it is probable that the electrons travel on the backs of the atoms in the liquid. All liquid conductors of this kind are called *electrolytes*. There is a third way of transfer. Water, for example, sometimes comes to us without either pipes, or carts, or any other carrier; for example, as rain-drops. This is the way in which electrons travel in a vacuum tube, where they are free from all encumbrance or association with matter.

Acids, Alkalis, Salts.—Before plunging into the case of electrolysis, as it is called, let us glance at the constitution of the liquids we are to use. We need a little chemistry to help us.

Chemistry recognises three classes of substances in this department: acids, alkalis, salts. Acids are sour bodies. Alkalis are soapy. Salts are saline, as we say: they are formed from a combination of acids and alkalis. Examples are (1) sulphuric acid and potash form sulphate of potassium, (2) nitric acid and soda form nitrate of sodium.

The salts, etc., referred to in the following sections are cyanide of silver, nitrate of silver, sulphate of nickel, sulphate of iron.

We will now try to give some idea of the practice

of electroplating and similar arts, first describing the preliminary operations which are necessary for success.

Preliminary Treatment.—In the first place it is absolutely necessary that the surface to be plated should be clean. The word clean must here mean more than it usually does. If, after preparing the surface, it be touched by the hand of the operator, the contact is sufficient to contaminate it: it is made "dirty" again. The art of cleansing is therefore of great moment.

The first process is to remove gross dirt by rubbing with emery powder or sand. This is followed by using a scratch-brush, that is, a brush in which bristles have been replaced by wire.

The next step is to get rid of all traces of grease, which is done by placing in a boiling solution of potash for a minute or so. The articles are then rinsed and placed in a bath of sulphuric acid mixed with nitric, the object being to remove any oxides or rust. They are then rinsed in water and at once placed in the plating bath. Special metals may want special preparation. For the silver bath, zinc and iron are frequently coated with a film of copper before they go in. Britannia metal, tin, and pewter are not placed in acid to cleanse them. After being placed in boiling potash, they may go straight into the silver bath, but are frequently first given a slight coating of silver in an extra bath containing more cyanide than usual and employing a stronger current for a few minutes.

Copper, brass, and German-silver are the easiest to deposit silver on; yet the two latter are often put in a bath of mercury, nitrate, or cyanide to coat them with a thin film of mercury. Simple immersion is enough. This is known as "quicking." After getting this film they are plated as usual.

Silver Plating.—The salt used is a cyanide of silver,

formed by the union of silver and hydrocyanic acid. The compound is represented by the letters AgCN, where Ag represents an atom of silver (argentum), C an atom of carbon, and N an atom of nitrogen.

The silver cyanide is not soluble in water. To form an electrolyte it is dissolved in a solution of potassium cyanide. The general method is this : Take a sufficient quantity of nitrate of silver and dissolve in water, and carefully add potassium cyanide solution. This precipitates the silver as a solid white cyanide, leaving nitrate of potassium in solution.

When the last addition throws down no more cyanide of silver, the liquid is poured off; the cyanide is rinsed several times with water, which is also poured off, and the silver salt is then dissolved in a solution of potassium cyanide. The proportions vary very considerably. An *average* value may be given. Distilled water, 1 gal.; potassium cyanide, 1 lb.; cyanide of silver, 3 or 4 oz. (equal to about $2\frac{1}{4}$ or 3 oz. of silver). To form the solution take half the water and dissolve the potassium cyanide. Then add the silver cyanide, and when this is dissolved add the rest of the water.

A good plating solution may be prepared by taking a solution of potassium cyanide (3 oz. to 1 gal.), and sending a current from a large silver + plate to a small silver cathode. When silver deposits add cyanic acid and proceed as below.

The plating solution thus prepared is put in a suitable vessel (Fig. 81). Wood may be used for this, but wrought-iron is better, especially if it be given a lining of thin wood. A wooden rim is fixed round the top, and brass bars are fixed to run from one end to the other. The alternate bars, 1, 3, 5, etc., are connected together, and have silver plates suspended from them by wires. A binding screw on the first

bar enables them to be connected to the positive end of the battery. They form what are called the anodes; the current enters the liquid by them.

The other bars, 2, 4, 6, are connected together, and also to the negative end of the battery, and from them are suspended the articles which are to be electro-

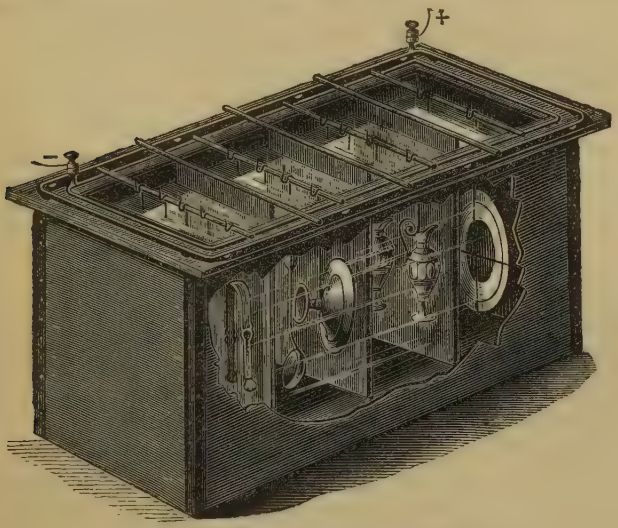


Fig. 81.—Electroplating bath.

plated. The current is adjusted according to the surface of the goods to be plated: about $\frac{1}{6}$ of an ampere for 16 square inches of surface, or say $\frac{1}{8}$ of an ampere for 1 tablespoon. The current is continued till the deposit is considered thick enough. A usual thickness is somewhat less than 1 oz. of silver per square foot of surface, which means that the silver is about $\frac{1}{1000}$ of an inch thick.

Of course, silver is dissolved from the positive plate

at the same rate at which it is deposited on the other. Silver atoms are travelling one way and cyanogen atoms (CN) the other way. It is therefore easy to see that the cyanide tends to increase round the anode, and get weaker round the cathode (the name for the conductor by which the current leaves the liquid). To remedy this the solution is stirred, or the cathode rod, carrying the spoons, forks, etc., is given a slight to-and-fro movement. In this way the different parts of the liquid are kept mixed.

Subsequent Treatment.—When the articles are taken out of the bath they generally present a white, frosted appearance: they have to be washed, dried, polished or burnished. The washing must remove every trace of the plating solution, and is made more perfect by rinsing first in water, then in dilute sulphuric acid, and lastly in water again. They may then be treated with the scratch-brush and dried in hot boxwood sawdust; or they may be given a bright surface by going over them with a hard steel burnisher.

The deposited silver may be made to come down with a bright and polished appearance, and the trouble of subsequent polishing saved. This is done by adding a *small* quantity of carbon bisulphide to the plating solution. Care must be taken to add no more than is necessary.

In case the reader may be tempted to try silver-plating for himself, we may point out one or two things which often trouble a beginner.

Sometimes the current dwindles down to nothing, and deposition stops long before the operation is over. This is generally traceable to an insoluble deposit on the silver anode, caused by an insufficient quantity of potassium cyanide in the bath. The addition

of 2 or 3 oz. of potassium cyanide per gallon ought to remedy this.

Again, the silver deposit may strip off as soon as it comes to be burnished. This is often due to an excess of potassium cyanide, and can be corrected by adding silver cyanide and water to the bath.

Further, in trying to get "bright" silver by adding carbon bisulphide to the solution, an excess is often added, and the silver comes down dull, even brownish, and, it may be, spotted. This is a difficult fault to correct. It is not easy to remove the excess of carbon bisulphide. One of the easiest ways is to add an equal quantity of plating solution to which no bisulphide has been added. This reduces the proportion to one-half, and may put it right, unless, indeed, the excess is very great.

All liquids containing cyanides must be handled with the greatest care, as they are exceedingly poisonous. Special care must be taken that no trace of a cyanide gets into any cut or abrasion of the skin.

Copper Plating.—In the modern industrial world there is a great demand for plating various metals with copper. In some cases copper has to be deposited as a preliminary to silverplating, in others it is done to give a non-corrodible surface to other metals, such as iron.

The most convenient electrolyte is a solution of copper sulphate containing a little free sulphuric acid. Five parts of copper sulphate by weight, 1 of sulphuric acid, and 20 of water make a good solution; but iron, steel, zinc, tin, lead, and Britannia metal cannot be placed in this solution without decomposing it, and they have to be given a thin coating of copper by working in a cyanide solution. Two gallons of water, $\frac{1}{2}$ lb. copper acetate, $\frac{1}{2}$ lb. potassium cyanide, and $\frac{1}{4}$ lb.

sodium sulphite will serve. The articles are cleaned, etc., by the process described under preliminary treatment, and then given a slight coating in the cyanide bath. They are then rinsed in water quickly and transferred to the acid sulphate bath, where the thickness of the deposit can be brought up to the desired standard. Great care is taken to control the density of the current. For the acid sulphate this ought not to exceed 1 ampere for each 20 inches of surface. If the density be too great the copper comes down in a very uneven way; the surface is not smooth, but covered with nodules of copper.

Greater regularity is secured if the liquid is kept moving over the face of the cathode, and higher current densities may then be used. One way of securing movement is by rotating the cathode at a good speed. The explanation of this improvement is very interesting, and arises naturally from the way in which the deposition takes place. When the copper is deposited in a liquid at rest, the film of solution at the face of the cathode contains less metal than usual. Hence the later deposit takes place from a weak solution, and one into which the stronger liquid is constantly diffusing. This leads to streaks of weaker and stronger liquid close to the depositing surface, with consequent irregularity. But when the liquid is made to move, the motion continually mixes the weaker and stronger parts, and so keeps a uniform liquid even at the depositing face.

Copper Refining.—An enormous amount of copper is required every year for the various purposes of the electric engineer. Copper is the best conductor for him; the only metal which comes near it is aluminium. But such copper as he uses must be very pure, otherwise its conductivity is seriously diminished. Now it

so happens that electrically-deposited copper is purer than any other; it is therefore of higher conductivity than other brands, and is demanded for all electrical work. The electrical method of refining is simple.

A wooden tank, lined with lead or bitumen, is filled with an acid solution of copper sulphate. In this is placed a number of thick slabs of commercial copper obtained by the ordinary metallurgical methods. These are shown shaded in Fig. 82, and form the anodes. Alternating with them is a similar number

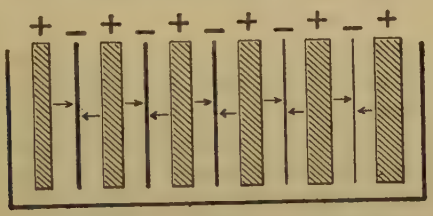


Fig. 82.—Copper refining by electrolysis.

of thin plates of pure copper, which form the cathodes. The thick impure slabs are connected to the positive terminal of a dynamo, the thin cathodes to its negative terminal. The current flows, as shown by the arrows, from both faces of each anode to the opposing face of the neighbouring cathodes. Consequently the anodes lose copper, the cathodes gain it. The deposited copper is pure; that eaten away is impure. Of the impurities, iron and a few other metals dissolve in the liquid and accumulate, but are not deposited unless the current is too strong, because copper sulphate is decomposed more easily than the iron compound. Nevertheless, after a time the solution contains too much impurity, and has to be renewed. Other impurities in the anode, such as silver, gold, etc., do

not dissolve. They remain behind as a black mud on the anode, and slowly fall to the bottom of the tank. When a sufficient quantity of this mud has accumulated it pays to recover the silver and gold contained in it; in fact, the sale of the precious metals thus recovered may cover the cost of refining.

The method of joining all the anodes to the same terminal is known as the multiple system, and is sometimes replaced by a "series" method. In this all the plates are alike, and consist of rolled slabs of impure copper. The first and last are joined to the terminals of the dynamo, and the current passes in one direction only down the tank. Each slab (except the first and last) acts, therefore, in two ways. On one face the current enters and copper is deposited; on the other face the current leaves it and copper is eaten away. Hence the slab increases on one face with pure copper, while impure copper is leaving its other face. At the end there remains only pure copper, with a small thickness of mud and impurity. This useless matter can easily be removed.

Dynamos for Refining.—The refining operation requires large currents. Even 5,000 amperes deposit only about 3 oz. of copper per minute, or say 11 lb. per hour. To refine tons of copper is a work of many refining cells working for a long time. Fortunately the pressure required is only a fraction of 1 volt for each cell, so that many cells can be put in series without calling for more than 20 or 30 volts. This determines the character of the dynamos employed. Their armatures are wound with large copper bars instead of wire, so that the enormous currents may be carried without undue heating. Such large bars as these make it impossible to get many of them on the armature, and hence the voltage is low, but we

have just explained that only low pressures are required.

Nickel Plating.—The solution used is a double sulphate of nickel and ammonia; the anode is a plate of nickel, and the procedure much as before. The solution is often warmed, and is generally more difficult to manage if we are to obtain a deposit which will stand rough usage. To prepare the solution 2 oz. of the double sulphate are dissolved in 2 pints of water, and about 1 oz. of boric acid is added. There is some advantage in placing a small piece of gelatine in the liquid.

The current ought to be weak, especially after the first deposition. For each square inch of receiving surface the current must not exceed one-tenth of an ampere at the beginning, the pressure being about 4 volts. As soon as the surface has got a thin coat of nickel the pressure is reduced and the current density is brought down to about one-fiftieth of an ampere per square inch. This is allowed to continue for one, two, or three hours, according to thickness of deposit desired. The plated article is rinsed well, dried and polished in a lathe, rubbing with a special polishing powder applied very gently.

Electrotyping.—This is the name given to any picture or type which is prepared for the printer by an electrolytic method. In electroplating the deposited metal is fixed to that on which it is deposited; in electrotyping the metal is deposited on a mould, from which it is separated immediately afterwards.

Electrotyping is used to obtain copper duplicates of engravings and to copy type which has been set up. The general process is as follows. The surface to be copied is placed in a hydraulic press along with a metal plate covered with wax, and is then pressed

until the wax has taken an impression of every detail of the surface. This wax impression is then rubbed with graphite in order to make its surface conduct (and also to prevent the wax from adhering to the surface it copies), and placed in a solution of copper sulphate. A current is now passed through the liquid on to the graphited surface. In other words, the wax impression is made the cathode in a copper-plating bath and copper slowly deposited until the wax impression is covered with a copper impression of it. This, by a double reversal, will be an exact reproduction of the original surface. After a sufficient thickness has been obtained the copper is removed and stiffened by having type metal cast on its back to make it a fairly thick block suitable for use in the printing press. The waxed surface does not always conduct well, even though coated with graphite; it is therefore sometimes coated by other means.

Aluminium.—This metal is now prepared electrically by a process which carries on electrolysis in an electric furnace. The substance electrolysed is dissolved, not in water, but in a salt named cryolite which has been melted in a furnace.

Cryolite is a white solid substance, and consists chemically of three elements—aluminium, sodium, and fluorine. The symbols for it are Na_3AlF_6, indicating that its molecule or smallest part contains three atoms of the metal sodium, one atom of aluminium, and six atoms of the gaseous element fluorine. This substance is not decomposed, but plays the same part here that is taken by water in the previous cases.

Alumina is a white powder, an oxide of aluminium (Al_2O_3), so that it contains three atoms of oxygen to two of aluminium. The cryolite is first melted by the heat of an electric arc; alumina is then dissolved in it,

and a current sent through the intensely heated solution.

Fig. 83 is a diagram of the arrangement. The iron crucible *i* is lined with carbon C, and this serves as a cathode, being connected to the negative terminal of a dynamo. The anode A is a group of carbon rods clamped together and arranged so as to be easily raised or lowered.

The workman begins by bringing the anode in contact with the bottom of the crucible to start a current, and then raises the carbon slightly to establish an arc (*see* arc lamps, p. 105). After a moment or two the lower part of the crucible is intensely hot, and soon melts a quantity of cryolite which is now thrown in. When a "bath" of melted cryolite is ready, alumina is thrown into it and dissolved. The electric current flowing through this solution decomposes it; aluminium and oxygen are the two substances formed. Consequently aluminium is carried downwards through the liquid and deposited in a molten state against the cathode C. Oxygen moves upwards to the carbon anode A, and, uniting with it, burns it into carbonic acid gas. The liquid slowly loses its alumina because of this process, and the anode gets shorter because its lower end is burnt away. The melted cryolite is unchanged. The workman has to counteract these changes, which he does by feeding in fresh alumina from time to time, and by adjusting the anode so that its lower end remains below the surface of the fused liquid.

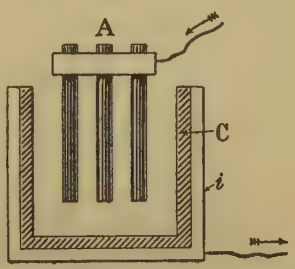


Fig. 83.—Aluminium furnace.

In this way aluminium accumulates at the bottom of the crucible, and is kept melted by the heat of the electrolysis going on above.

Fig. 58 (page 87) shows how the small Borcher's furnace described in the furnace section can be adapted to the manufacture of aluminium.

Preparation of Gases.—There is one application of electrolysis which can hardly be described under the head of electroplating, because the product is a gas, or rather two gases. Yet the commercial importance of these gases makes it necessary to say a word about them. When dilute sulphuric acid is electrolysed, using platinum electrodes, bubbles of gas are liberated at both anode and cathode. The unaided eye cannot see any difference between these gases, though it is easy to see that the quantity of gas at the cathode is greater than that at the anode.

The gases may be collected as in Fig. 84*a*. The liquid is dilute sulphuric acid, say one volume of acid to twelve of water. P_1 is the anode, P_2 the cathode. The tubes T_1 T_2 are placed so as to collect the gases which come from the electrodes. These tubes have been filled with water (or with dilute acid), and then inverted in the general body of liquid. They remain full of liquid by reason of the pressure of the air on the general surface.

The electrodes P_1 P_2 are usually made of platinum. A cheap substitute is a couple of lead wires rather more than $\frac{1}{8}$ inch thick. They are covered with india-rubber tubing, except at the free vertical ends. This is to limit the action to that part, and so secure all the gas which is evolved.

As soon as the electrodes are joined to a suitable battery (8 to 12 volts) gas bubbles appear on them and rise into the tubes. After a time T_2 is full; T_1 only

half full. Examination of T_2 can proceed while T_1 is filling.

Gas from cathode T_2.—Light a taper; remove T_2 from the vessel, holding it mouth downwards, and plunge the taper upwards into the gas. The taper goes out; the gas takes fire at the *mouth* of the vessel. If the tube be turned so that its mouth is upward, the gas and flame rise quickly, showing the lightness of the gas. Evidently the gas is light, in-

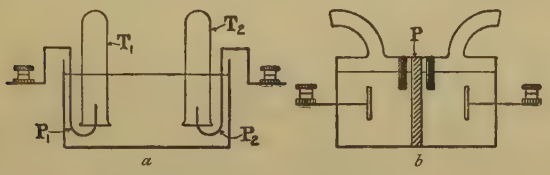


Fig. 84.—Preparation of gases from water.

flammable, and a non-supporter of combustion. It is, in fact, the well-known gas called *hydrogen*.

The gas from the anode can also be examined by a burning taper when T_1 is full, though it must not be held mouth downwards. As soon as the taper is inserted its flame becomes much more fierce, and it is clear that this gas from the anode is an energetic supporter of combustion. If a glowing taper (one with only a spark on the end) be inserted, the glow at once bursts out into a flame. The gas is oxygen, the commonest and most active element in Nature.

The net result of this experiment is to show that dilute sulphuric acid is split up by a current into these two gases. Both of them can be prepared in many other ways which do not involve electrical appliances, but the electrolytic is in many cases the best, so that the older methods have been discarded.

Of course, the apparatus is not so small or simple as that shown in the figure. The two gases must be evolved continuously and yet separately. A diagram of the arrangement is shown in Fig. 84*b*. The containing vessel is divided into two by the porous partition P, the pores of which are full of the liquid and therefore conduct the current. The liquid is a solution of soda—not acid—and the electrodes are made of iron. The top is closed except for an outlet pipe in each compartment, through which the gases are led away to suitable receivers and stored ready for use. For sale they are compressed in steel cylinders, and sent out for lime-light and other exhibitions, etc.

Theory of Electrolysis—Ions.—The inner mechanism and action of an electroplating solution is very interesting. We have already said that the electrons are here carried by material particles, and it is desirable that the nature of these carriers should be clearly apprehended. We will therefore explain Faraday's list of words intended to elucidate this subject. They are as follows :—

Electrolysis.—An abbreviation of electrical analysis, because it always involves an analysis or splitting up of the dissolved body.

Electrolyte.—Any liquid which is split up in a regular and easy manner by the passage of an electric current. Some liquids (benzene, for instance) are decomposed, but only by violence and extreme pressure. These are rather like insulators.

Electrodes.—The conductors (like c_1 c_2 in Fig. 85) by which the current enters and leaves the liquid.

Anode.—A special name for the electrode by which the current *enters* the liquid.

Cathode.—A special name for the electrode by which the current *leaves* the liquid.

Ions.—A general name for the substances formed when the current splits up the electrolyte. Copper sulphate, for example, is split up into two ions—copper and sulphion (*see* next section, page 151).

Anion.—A special name given to the ion which travels towards and is liberated at the anode.

Cation.—A special name given to the ion which travels towards and is liberated at the cathode.

The full meaning of these names can only come home to the reader by the use of several examples. Let us therefore take an ordinary salt, such as common table salt, and consider it in relation to electrolysis. It is a compound body, containing two elements, a metal named sodium and a gas named chlorine. The proportion in which these are combined is 23 parts of sodium to 35 of chlorine. It is more interesting, however, to state the composition in atoms. One atom of sodium unites with one atom of chlorine to form one molecule* of table salt. (The weights of the two atoms are in the proportion of 23 to 35.)

Now the molecule of salt, like every other substance, contains equal quantities of positive and negative electrons. But there is one great peculiarity about it which it shares with all electrolytes: *The electrons are not equally divided between the sodium and the chlorine.* The chlorine has an excess of one negative electron; the sodium has an excess of one positive electron. Electrically the molecule can be represented thus: (+) (−), the + indicating sodium and the − chlorine.

When they are acted on in a liquid the electric forces separate the atoms—the sodium is driven in one

* A molecule is the smallest material part of a body known to physicists; an atom is the smallest material part of an elementary body.

way and the chlorine in the other. Each carries its little electric charge of one electron, and so the electrons are conveyed from one electrode to the other. The sodium and chlorine atoms are the ions, sodium being the cation and chlorine the anion.

Another case is that of copper and sulphuric acid. Let two copper plates c_1 c_2 (Fig. 85) be placed in dilute sulphuric acid and a current sent through, as shown by the arrows, from c_1 to c_2. After a while the liquid will be coloured blue, and copper will begin to deposit on c_2. The other plate c_1 is eaten away, and after a while would entirely disappear. The increase in weight of c_2 is nearly equal to that lost by c_1, but not quite: for some of the copper exists in the liquid in the form of copper sulphate. It is this substance which gives the blue colour.

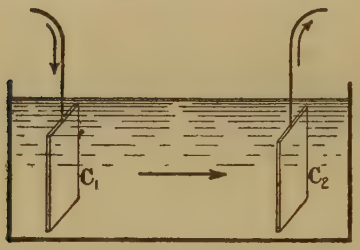


Fig. 85.—Copper plates in copper sulphate solution.

The noteworthy thing is that both electricity and copper have been passing into the liquid at c_1 and *both have travelled* to c_2. It is not difficult to show that acid has been travelling in the opposite direction, carrying a negative electron with it.

The reader may observe that in this last case a plating solution is formed by the electric current itself. Its first effect is to change the sulphuric acid into sulphate of copper, and then carry the copper right through the liquid to the cathode. Other plating solutions can be formed in a similar manner.

Tables I. and II. contain a list of the ions mentioned in our experiments. They also give the symbols by which chemists commonly write down the atom of each. The elements are here classed on an electrolytic basis, being divided into anions and cations. It does not follow that the atoms have these special electric charges when they enter into compounds which are not electrolytes.

TABLE I.

CATIONS, OR IONS WHICH CARRY A POSITIVE CHARGE.

Name.	Symbol of atom.	Relative weight of atom.	Equivalent weight.
Hydrogen	H	1	1
Sodium	Na	23	23
Potassium	K	39	39
Silver	Ag	108	108
Iron	Fe	56	28
Nickel	Ni	58·6	29·3
Copper	Cu	63·5	31·7
Zinc	Zn	65·4	32·7
Tin	Sn	118	59
Lead	Pb	207	103·5
Gold	Au	196·5	65·5
Aluminium	Al	27·3	9·1

TABLE II.

ANIONS, OR IONS WHICH CARRY A NEGATIVE CHARGE.

Name.	Symbol.	Relative weight of atom.	Equivalent weight.
Oxygen	O	16	8
Nitrogen	N	14	4·66
Chlorine	Cl	35	35
Bromine	Br	80	80
Iodine	I	127	127
SO_4	SO_4	96	48
NO_3	NO_3	62	62
CN	CN	26	26

Most of these symbols are taken from the Latin names of the metal; Ag, for instance, being from argentum, the Latin name for silver, and K coming from kalium.

This list contains three ions which are compounds. They are the negatively-charged part of sulphuric, nitric, and cyanic acids.

The meaning of the equivalent weight can be made fairly clear. It is the proportion in which the element commonly combines with other elements. The elements do not always unite atom to atom; sometimes it is one atom of a cation to two of an anion. For example, one atom of copper unites with two of bromine, the symbol of copper bromide being $CuBr_2$. This means that one atom of copper carries as many electrons as two atoms of bromine; the number of positive electrons carried by an atom of copper is equal to the number of negative electrons carried by *two* atoms of bromine—that is, two.

One atom of copper is thus equivalent to two atoms of bromine or chlorine, and its equivalent weight is half its atomic weight.

This will appear most profoundly interesting if we give the quantity of each ion deposited by one coulomb of electricity, and still more so if we compare the weight deposited by 96,600 coulombs, this being the number which deposits 1 gramme of hydrogen, as in Table III.

The last two columns are here identical, and therefore of great significance. For it means that the same quantity of electricity is always found with the quantities of elements that unite together, and it suggests most powerfully that what we call chemical combination is after all merely a union of positive electricity on one atom with negative electricity on some other.

TABLE III.

Ion.	Symbol.	Weight deposited by 1 coulomb.	Weight deposited by 96,600 coulombs.	Equivalent weight found by chemist.
Hydrogen ...	H	0·0000104 gram.	1 gram.	1 gram.
Sodium ...	Na	0·000239 ,,	23 ,,	23 ,,
Potassium ...	K	0·000405 ,,	39 ,,	39 ,,
Silver... ...	Ag	0·001118 ,,	108 ,,	108 ,,
Iron	Fe	0·00029 ,,	28 ,,	28 ,,
Nickel ...	Ni	0·000304 ,,	29·3 ,,	29·3 ,,
Copper ...	Cu	0·000328 ,,	31·7 ,,	31·7 ,,
Zinc	Zn	0·000338 ,,	32·7 ,,	32·7 ,,
Tin	Sn	0·000612 ,,	59 ,,	59 ,,
Lead	Pb	0·00107 ,,	103·5 ,,	103·5 ,,
Gold	Au	0·00068 ,,	65·5 ,,	65·5 ,,
Aluminium ...	Al	0·000095 ,,	9·1 ,,	9·1 ,,
Oxygen ...	O	0·000083 ,,	8·0 ,,	8·0 ,,
Nitrogen ...	N	0·0000485 ,,	4·7 ,,	4·7 ,,
Chlorine ...	Cl	0·000367 ,,	35 ,,	35 ,,
Bromine ...	Br	0·00083 ,,	80 ,,	80 ,,
Iodine ...	I	0·00131 ,,	127 ,,	127 ,,

In this way it may ultimately be found that what is called chemical affinity is a form of electric attraction.

Ions in Practical Work.—The ions which take part in ordinary practical electrolysis are now easily stated :—

Silverplating.—Salt. Silver cyanide (AgCN). Positive ion, Ag; negative ion, cyanogen (CN).

Nickelplating.—Salt. Sulphate of nickel and ammonia ($NiSO_4 + Am_2SO_4$). Positive ion, Ni and Am_2; negative ion, SO_4. The ammonia remains in solution and recombines.

Copper refining.—Salt. Copper sulphate ($CuSO_4$). Positive ion, Cu; negative ion, SO_4.

Aluminium.—Salt. Fluoride of sodium and aluminium ($AlNa_3F_6$). Positive ion, Al and Na; negative ion, fluorine (F). This salt serves merely as a vehicle for aluminium oxide.

The Mystery of Electrolysis.—If a solution of copper sulphate be electrolysed for a long time the final result is that all the copper is deposited on the cathode, while all the acid is brought to the anode. Obviously the copper has been travelling in one way, the SO_4 in a contrary direction.

In this connection there arises a great mystery: *No one has ever been able to see these ions travelling*

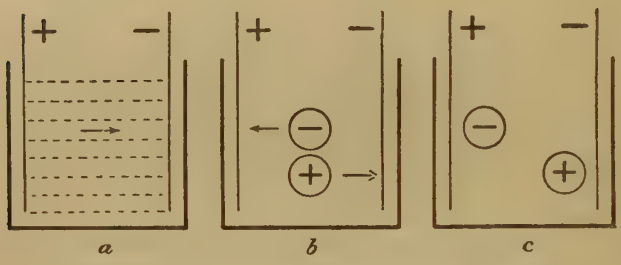


Fig. 86.—Separation of ions by electric field.

in their different ways. How does the copper atom get transferred from one electrode to the other?

The point of this question is brought out by Fig. 86. In Fig. 86*a* the electrodes are supposed to be joined to a battery; one of them is charged positively, the other negatively, and they set up an electric field in the liquid. This is shown by the dotted lines, the arrow indicating the direction of the field, that is, the direction in which positive electricity will be urged. Now let an electrolytic molecule be represented as in Fig. 86*b*; the + ion will be urged to the right, the − ion to the left. In obedience to this they will be separated, and appear at the electrodes as in Fig. 86*c*. All this is clear, but the question is: How is it that the ions are

never detected in transit.? How is it that they cannot be detected until they get to the electrodes?

The answer is obtained by supposing that the ions travel through the liquid like partners in a dance. Each positive ion moves to the right, not as a free ion, but by uniting successively with different negative ions. Fig. 87 gives an idea of this. The ions are numbered 1, 1; 2, 2; and so on. Fig. 87A shows them before electrolysis begins.

After the first decomposition one negative ion is set free at the anode, one positive ion at the cathode; but these two particular ions are not derived from the

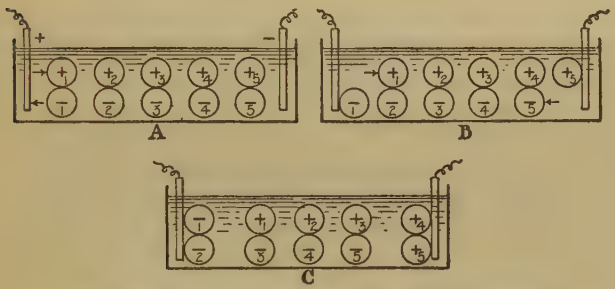


Fig. 87.—Wandering of ions during electrolysis.

same molecule. It is the number one anion and the number five cation which are set free. The other ions have re-combined as shown in Fig. 87B. The action is carried a stage farther in Fig. 87C, where two cations are set free (Nos. 4 and 5) and two anions, Nos. 1 and 2). Thus there is a chain of decompositions and combinations. This is known as the Grotthus chain, Grotthus having been the first to suggest this explanation.

Voltameters and Coulombmeters.—One of the most interesting applications of electrolysis is found

in the measurement of electricity itself. On page 55 it was stated that the weight of silver deposited depends on the quantity of electricity passed, and could therefore be used to measure it. It will give interest to the subject if we indicate how this was proved. Faraday, to whom the proof is due, used dilute sul-

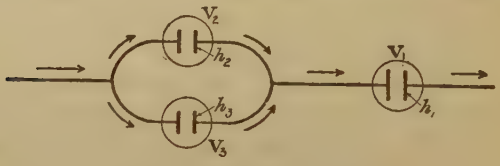


Fig. 88.—Faraday's proof.

phuric acid as the electrolyte and platinum for the electrodes. He first proved that the amount of gas liberated did not depend on the size of the metallic electrodes. If the same current was sent through two vessels, one with larger and the other with smaller electrodes, the gas liberated in the two was equal.

Secondly, the gas liberated increased with the time. A given current liberated twice as much gas in four minutes as in two.

Thirdly, a current was divided between two branches, as in Fig. 88. Vessels v_2 v_3 were placed in each branch, and a third v_1 in the main circuit. A battery maintained a current, its direction being shown by the arrows. Hydrogen gas was liberated at the plates h_3, h_2, h_1 and was collected. Necessarily the current through the two branch circuits must be equal to that in the main. Faraday reasoned that the quantity of electricity passed through v_2, added to that passed through v_3, must equal that which passed through v_1. The question was: Would the hydrogen liberated at h_2, added to that at h_3, equal

that at h_1? Faraday found that it was so in every case, and he was therefore enabled to draw the conclusion which lies at the basis of electrical measurement. He called the measuring instrument a volta-electrometer, a name that was soon abbreviated to *voltameter*.

The word voltameter is now applied to every form of apparatus in which electricity is measured by the deposition of an ion. In recent times these have become very numerous, and it is usual to speak of them by naming the ion. Thus we have the copper voltameter and the silver voltameter; the hydrogen voltameter is commonly called the sulphuric acid voltameter. In measuring electricity by copper the electrolyte is copper sulphate; for silver it is silver nitrate, about 20 per cent. The silver method is the most accurate, but copper approaches it very closely if care be taken.

A very handy and expeditious instrument is shown in Fig. 89. A bottle containing dilute sulphuric acid is closed by a stopper, through which pass wires carrying two platinum electrodes. Two glass tubes G and S also pass through the stopper. G is graduated; S carries a stopcock.

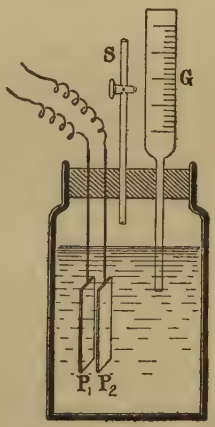


Fig. 89.—Coulombmeter.

If S be turned off, and the wires joined to a battery, gases are liberated, and as they accumulate under the stopper they press the liquid up into G. Here the graduations give the means of measuring the coulombs and, indirectly, the amperes. One coulomb liberates a certain

volume of mixed gases, 0·17 of a cubic centimetre (about $\frac{1}{100}$ cubic inch). The tube can therefore be graduated to show how many coulombs have passed. Thus the first mark being called 0, the second is called 10, and is so fixed that 1·7 cubic centimetres of liquid will fill the space from 0 to 10. The third mark is called 20, and so on.

Now let a current pass; the liquid will slowly rise in G. Notice the time at which its surface gets to 0, then to 10, then to 20, and so on. It is easy then to say what time was required for 10 or 20 coulombs to pass, and thus to calculate how many coulombs passed in one second. This is the current in amperes.

Atomic Charges—Electrons.—It is possible to calculate the quantity of electricity on an atom. We have seen that 1 gramme of hydrogen carries 96,600 coulombs, and in 1 gramme of this element there are 1,000,000,000,000,000,000,000,000 atoms. The electric charge on one atom is therefore

$$\frac{96{,}600}{1{,}000{,}000{,}000{,}000{,}000{,}000{,}000{,}000} = \frac{1}{10{,}000{,}000{,}000{,}000{,}000}$$

of a coulomb nearly, say the one-ten-trillionth of a coulomb.

This is a *natural unit* of electricity. It is found not only on each atom of hydrogen, but also on each atom of metals like silver, sodium, potassium, etc. This unit has been known for many years, and remained of little moment till it was discovered that the same quantity appeared as the unit in the cathode rays of a good vacuum tube. The atomic charge of electricity in electrolysis is identical with the charge in one of the flying corpuscles of a cathode ray.

The question then arose: Is there an atom of matter united with the unit charge in the case of the

vacuum tube? Is the corpuscle an ion like the electrolytic-charged atom, or is it a separate and disembodied corpuscle of electricity? Professor J. J. Thomson proved that though the electric charge of a corpuscle was the same as that carried by an atom of hydrogen, there was no mass of matter with it comparable with that of an atom. In fact, the electric charge had been dragged off the atom by the high voltage used to get a spark through the vacuum.

From these results, and from the immense velocity with which the cathode ray particles travelled, Professor Thomson deduced the theory of electrons, as explained on page 24.

Our final conclusion and statement are therefore as follows:

Electricity is found in Nature in the form of electrons, each one of which is equal to the one-ten-trillionth of a coulomb. This quantity of electricity seems to be indivisible, and therefore a natural unit.

In a highly-exhausted vacuum tube these electrons are found in the cathode rays, and appear to be dissociated from ordinary matter altogether.

In an electrolyte the electrons are associated with atoms of matter, and each atom carries generally one free electron. In some cases it may carry two or even three.

In solid bodies the charge on the atom is not yet known. Indeed, there is no reason to say that the atoms have any free charge except that derived by analogy from what is said above as to gases and liquids.

CHAPTER VII

BATTERIES, CELLS, AND ACCUMULATORS

Simple Cell. — The secret of electric batteries is largely explained by the facts of electrolysis. Every cell contains an electrolyte, and the action cannot be understood unless we take into account the special way in which electrolysis takes place. The most noteworthy point is that the electrolysis is brought about by the cell itself, and not by an outside battery.

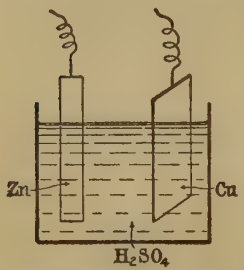


Fig. 90.—Simple cell.

Consider first a simple cell, Fig. 90 : Cu is a sheet of copper, Zn is a rod of zinc, the liquid is dilute sulphuric acid. If the zinc is pure or if it be amalgamated* nothing happens till the two metals are connected by a wire. As soon as a circuit is thus formed a current flows, internally from zinc to copper, externally from copper to zinc. The zinc is dissolved, forming zinc sulphate, while hydrogen is liberated against the copper. The reader will at once see the electrolytic changes which arise.

It is clear that there is some electromotive force produced by the contact of the metals and the acid. We cannot give more than a hint of the way in which

* An amalgam is an alloy of any metal with mercury. To amalgamate zinc, the metal is washed with acid and then dipped in mercury or rubbed with it.

it arises, and because of its incompleteness our statement cannot be exact. But it will help the reader to see how a cell can set up a flow of electrons in the circuit.

There are three substances concerned: zinc, copper, and acid. The zinc and copper contain equal quantities of both electrons. So also does the acid, but we have to remember that in the molecule H_2SO_4 there is an excess of positive on the hydrogen and an equal excess of negative on the (SO_4).

Now note that the (SO_4) has a greater affinity for zinc than for copper, and will turn towards it, carrying its excess of negative with it; the hydrogen at the same time turns towards the copper, carrying its excess of positive with it. The result is to push positive electrons to the copper and negative to the zinc. The metals thus become charged, and when joined by a wire a current flows. This current is due to electrolytic changes occurring in the liquid; zinc is dissolving and hydrogen is appearing at the copper plate.

The work done by this current is obtained at the expense of the zinc. Its combination with the (SO_4) produces energy, and this is carried by the electrons (in the form of so many volts' pressure) to the various parts of the circuit. The quantity of electricity put into circulation depends on the quantity of zinc dissolved. One gramme of zinc yields 2,943 coulombs. The electric pressure or electromotive force is very nearly 1 volt.

The voltage of the cell depends on the degree of affinity between the metal and acid. Magnesium has a greater affinity for (SO_4) than zinc has; when it dissolves, more heat energy is produced. Hence, if a cell be made in which magnesium takes the place of zinc, its electric pressure or voltage will be greater. The voltage

is affected also by the other metal, such as the copper. If zinc and platinum be employed, we get the same quantity of electricity from, say, each gramme of zinc —namely, 2,943 coulombs, but they are endowed with a greater working power; the cell has a higher voltage than a zinc-copper cell. The reason for this is not easy to give in an elementary way; it is connected with the fact that platinum is less easily burnt than copper.

Faults of Simple Cell—Polarisation.— As we have seen, when zinc dissolves in a simple cell, hydrogen is liberated on the copper. The effect is to cover the copper more or less with hydrogen and to that extent change the surface. In an extreme case we might say that the result was to change the cell from zinc-copper to zinc-hydrogen. Now the deposition of the gas alters the electric pressure. For example, as soon as the hydrogen begins to appear, the pressure of a simple cell falls from 1 volt to 0·9, then 0·8, and so on to, say, 0·5 volt or less. At the same time, and necessarily, the value of the current also falls. This effect of hydrogen in lowering the voltage of a cell is known as "polarisation." In the early days, when simple cells were the only known way of getting electric currents, polarisation was the greatest difficulty in the way of experiment, and its prevention began to exercise the best minds. It will help the reader in studying this section to note that nearly all the improvements in batteries and all the variations of the different forms are attempts to reduce or to abolish polarisation. For the last hundred years it has been evident that a cell could not give a constant current unless polarisation could be prevented, and the makers of cells have asked themselves: "How can hydrogen gas be prevented from appearing on the copper or similar plate?"

We shall show how this is done in three different cases. Other cells will then be fairly easy to understand.

Daniell Cell.—Fig. 91 shows one form: J is the containing jar. The zinc rod Z stands in dilute sulphuric acid, held in a porous pot P. Outside this is a solution of copper sulphate, in which stands the copper cylinder C. When an atom of zinc dissolves, the series of ions begin to exchange partners, as usual, and hydrogen travels towards the copper. But it does not get beyond the porous partition, because the series of exchanges is continued by the *copper* ions of the copper sulphate instead of the hydrogen ions of the acid. Hence copper ions travel towards the copper plate and are deposited on it; the copper plate remains copper. Hence, also, hydrogen bubbles do not reach it. The polarisation is prevented; the cell maintains a steady pressure, and therefore also a steady current. Of course, the Daniell cell is made up in varied form. Sometimes it is made cylindrical and sometimes rectangular, but in all cases there is zinc in sulphuric acid, with a solution of copper sulphate intervening between this and the copper plate.

Fig. 91.—Daniell cell.

The quantity of electricity available for circulation depends on the weight of zinc which can be used. Each grain dissolved circulates 197 coulombs. The current—that is the rate of flow—depends on the electromotive force (or pressure) of the cell and the resistance of the circuit, including that of the cell itself. The pressure is just over 1 volt, say 1·08 volt, though this varies slightly with the composition of the liquids.

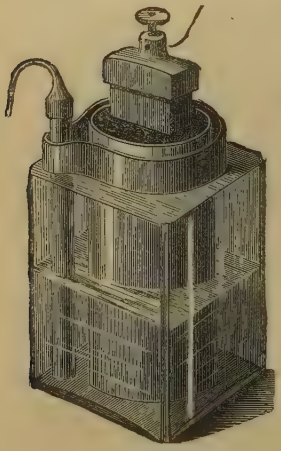


Fig. 92.—Leclanché cell.

Leclanché Cell.—In this zinc and carbon are the solid conductors employed, the liquid is a solution of a salt known as sal ammoniac. Fig. 92 shows one arrangement. The carbon block is in the middle of a porous pot, and is surrounded by granules of carbon and manganese dioxide in sufficient quantity to make the whole a compact mass. The manganese dioxide is a black stone found in the earth, and is provided in order *to burn up any hydrogen* that may be liberated at the carbon. Manganese dioxide is very rich in oxygen and is ready to yield up some of this.

When the cell begins to deliver a current, zinc dissolves and forms chloride of zinc, the other ions interchange partners, as usual, with the final result that ammonia and hydrogen are liberated and threaten to polarise the cell. But the manganese at once begins to oxidise the hydrogen, that is, to change it into water.

Unfortunately, manganese dioxide does not burn up

hydrogen quickly, so that if the current be fairly strong the hydrogen accumulates and polarises the cell. On resting, however, the cell depolarises, for repose enables the manganese to go on silently burning away the excess of hydrogen bubbles. The cell, therefore, *recovers* itself.

These features of the Leclanché cell make it eminently suitable for electric bell work, where a weak current flows for a moment and is followed by an interval of repose. A demand like this can be met by the somewhat feeble depolarising power of the manganese dioxide. For steady, continued currents of any appreciable magnitude, however, a Leclanché cell is not adapted.

Here, as in other cases, the quantity of electricity the cell can circulate depends on the quantity of zinc which can be dissolved; 1 grain means 197 coulombs.

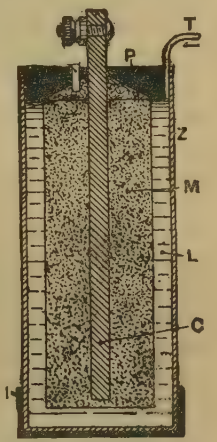


Fig. 93.—Burnley, or E.C.C., dry cell. (*The Electrician.*)

Dry Cells.—A dry cell is generally a modification of that invented by Leclanché, and is intended to do away with the liquid. Fig. 93 shows one variety, known as the E.C.C. cell. The outer vessel is a zinc cylinder Z, to which is soldered a wire T to form the negative terminal. A carbon rod C stands in the middle, and is packed in the middle of a black paste M. Lying outside this and separating it from the zinc is a white paste L. The black paste is a mixture of manganese peroxide and powdered carbon. The white paste is a mixture of plaster of Paris and flour. Both pastes are

moistened with a solution of sal ammoniac and zinc chloride. The whole is sealed at the top with bituminous pitch, through which passes a vent. The base 1 is a protecting shoe of millboard, but this is now extended to cover the whole of the zinc.

This cell is described as typical of dry cells in general. It is simpler than some of them, but gives a fair idea of their meaning and construction.

Accumulators.—The accumulator or secondary battery is the most useful of all batteries, and has displaced many forms which were formerly used. It is only a few special cases (like that of electric bell work) which are not better served by accumulators than by any other type.

There are three active ingredients in the ordinary accumulator, namely, spongy lead, spongy peroxide of lead, and dilute sulphuric acid. Supports are needed, one for the lead, one for the peroxide, and these are made of lead grids. The grids filled with spongy lead have the light blue colour of lead, and are known as the negative plates. Those which contain peroxide of lead are dark brown or chocolate coloured, and are called the positives. A cell generally contains several plates of each kind, interleaved though not touching: all the positives are joined together at one end; all the negatives at the other. (Figs. 94 and 95, Plate II.) Fig. 94 shows two cells for ignition work; Fig. 95 shows cells for lighting.

When properly prepared, and with acid whose density is 1,220 (one volume of acid to five of water), the pressure of this cell is just over 2 volts. Its power to deliver and maintain currents depends on the area of the plates: the larger the plate the greater the current it can maintain. The word "plate" here means the set of peroxides joined together on

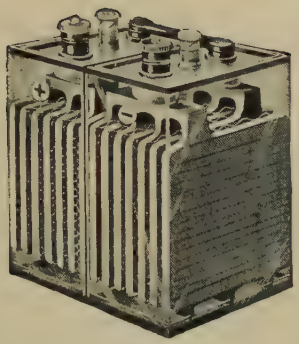


Fig. 94.—Accumulators for ignition (*Hart*)—*See p. 164*

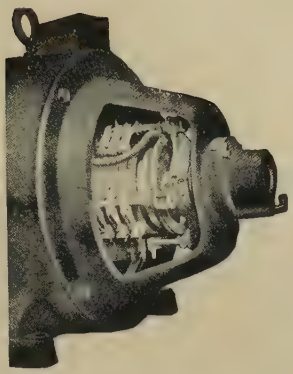


Fig. 152.—Semi-enclosed motor, armature end only (*General Electric Co.*)—*See p. 253*

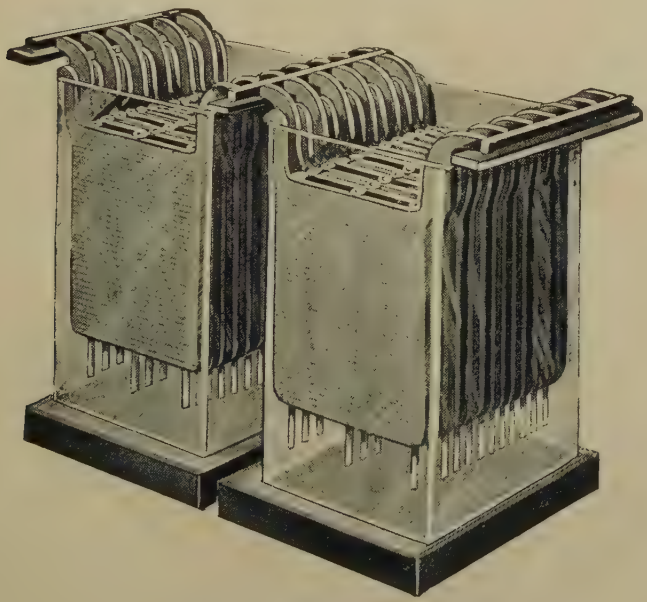


Fig. 95.—Accumulators for lighting (*Hart*)—*See p. 164*

the corresponding set of spongy lead. Each square foot of positive *plate* will deliver 6 amperes for about 6 or 7 hours.

Manufacture of Accumulators.—There are two distinct methods of making accumulator plates. One is known as the Planté method, the other as the "pasted" method.

"Pasted" Plates.—A grid is filled with a stiff paste, made of red lead and litharge mixed with dilute sulphuric acid and, after being thinned and made smooth, is put aside to dry. The paste for positive plates is slightly different from that used for negatives, but good results can be obtained by using similar pastes for both.

When dry the plates are placed in dilute acid (density 1,175), and an electric current from a dynamo is sent through from one set to the other. The plate by which the current enters has its paste changed to peroxide of lead; that by which the current leaves becomes spongy lead.

To understand this remember that the current through sulphuric acid using lead electrodes gives oxygen at the anode, hydrogen at the cathode. It is these gases which change the paste. The litharge and red lead used are oxides of lead, and we may represent the change by symbols. Pb stands for 1 atom of lead.

Litharge + oxygen = peroxide of lead.

$$PbO + O = PbO_2.$$

An atom of litharge contains 1 atom of lead and 1 atom of oxygen. When a second atom of oxygen unites with them the litharge is changed to the peroxide.

On the negative plate a reverse change takes place,

hydrogen removing the atom of oxygen from the litharge and leaving spongy lead.

$$\text{Litharge} + \text{hydrogen} = \text{lead} + \text{water.}$$
$$PbO + H_2 = Pb + H_2O.$$

The process of converting the litharge into peroxide on one plate and spongy lead on the other is called the "forming" process, and requires that the "forming" current shall be steadily maintained for more than 24 to 36 hours. It is also necessary to keep acid away from the unformed plates until the dynamo, etc., are quite ready to provide the forming current. If the plates are left unformed in the acid an injurious action takes place. When the forming is well done the positive plates have a rich dark brown colour, the negatives a fine light grey-blue.

Planté Process.—In its early form this is very simple, and consists in electrolysing sulphuric acid with continued reversal, using lead electrodes. These are slowly converted into peroxide and spongy lead. Stout sheets of lead, with appropriate lugs as terminals, are placed side by side in dilute sulphuric acid and a current sent from one set to the other *for a minute or two*. The result is that the sheet which acts as anode gets a very slight coating of peroxide. Some of the oxygen liberated by the current unites with the lead and peroxidises it. But the action is a mere surface action, and the quantity of peroxide exceedingly small. On the other plate the hydrogen does nothing; it simply escapes as bubbles. In order to make the further steps clear, we shall call the oxidised plate *a* and the other plate *b*.

Second step.—Current reversed: *b* is superficially oxidised; the peroxide film on *a* is reduced to spongy lead by hydrogen.

Third step.—Current again reversed: *a* is again oxidised, but more oxide is now formed than at the first: *b* is acted on by hydrogen, and its film of peroxide reduced to spongy lead.

Fourth step.—Current reversed: *a* has its peroxide reduced to spongy lead; *b* has its surface changed to peroxide once more, a larger quantity being formed than in the second step.

The further effects can be described in a few words.

At the fifth, seventh, ninth, eleventh, etc., reversal the surface of *a* is again peroxidised, a larger quantity being formed each time. At the same time the surface of *b* is reduced to spongy lead, larger quantities being formed at each successive reversal.

At the sixth, eighth, tenth, twelfth, etc., reversal the surface of *a* is reduced to spongy lead and that of *b* peroxidised. The final result is that a fair part of sheet *a* is converted into peroxide and an equal part of *b* has become spongy lead. At each stage the charging current has had to be continued for an increasing time, because it has had to do more work, having more oxide or lead to change. At the beginning a minute or two sufficed; at the end six or seven hours are needed.

The process is tedious, and in modern form is expedited by starting with plates whose faces are cut up by fine grooves, etc., so as to give large surface at once. The final result is a lead core covered by the peroxide on one plate and by spongy lead on the other. Both peroxide and spongy lead are porous enough for the acid to diffuse through them. After the right quantity of active material has been formed no more reversal of current must be allowed, otherwise the solid core of the plates will be eaten right through. The cell is now ready for use as a battery.

When an accumulator is used as a generator of current the spongy lead plays the same part as zinc in the other batteries, and forms sulphate of lead. The peroxide of lead plays the same part as the manganese dioxide in the Leclanché cell; it burns up hydrogen produced by the changes in the acid, and by doing this it prevents polarisation. When the cell is discharged, about half of the spongy lead has been changed to sulphate of lead; about half of the peroxide has also been changed to sulphate of lead; the acid has become much weaker, having lost the part now existing as sulphate of lead on each plate.

Appearance of a Discharged Cell.—The changes in the cell due to discharge are detectable in several

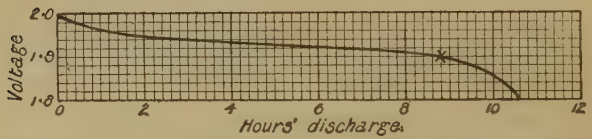


Fig. 96.—Curves showing fall of pressure during discharge.

ways. (*a*) By the colour of the plates. The peroxide has lost its rich dark brown and become brick red. The spongy lead has no trace of blue: it is now a dirty grey. (*b*) By the density of the acid, which has dropped from 1,210 to 1,175. (*c*) By the lower electric pressure, which has fallen from 2·05 to 1·8 volt. This fall is, however, not so marked unless the test is made while the cell is still working, that is, still delivering a current. It is noteworthy that the fall in voltage takes place chiefly towards the end of a discharge. Fig. 96 illustrates this. The voltage of a battery was read at intervals during a 10-hours' discharge, and the readings were plotted out on a sheet of ruled paper. The scale of volts is shown upwards; the lapse of time

by length measured from left to right. For example, at the end of 9 hours, working at 20 amperes, the pressure was 1·9 volts, as shown at the point on the curve marked x.

Apparent Recovery while Resting.— An interesting feature of a discharged accumulator is the way in which it apparently recovers from exhaustion when it is allowed to rest. Looking at the curve in Fig. 96, we see that just as the discharge is coming to an end the electric pressure is about 1·8 volt, and is rapidly falling. If now the discharge be stopped, so that the cell can rest, the pressure rises at once to something like 1·95 volt. This is likely to give the impression that the cell has recovered, but it is a false impression. If the discharge be recommenced the pressure falls *at once* to its previous low value. The fact is that when discharge is nearly or wholly complete, the pores of the active material on both plates are clogged by the sulphate of lead which has been formed, and the acid can no longer diffuse in *quickly enough* to keep the action going on. What rest does is to afford time for this diffusion of acid into the active material, and so cause the rise in pressure.

Recharging an Accumulator.— A peculiarity of an accumulator is its reversibility. When it is itself working and delivering a current, its active materials are gradually changed into sulphate of lead. This chemical change is undone if a current be sent through the cell *in a reverse direction.* The reversal of the current leads to a reversal of the electrolysis. Oxygen is brought to each positive plate and acts on the sulphate of lead in its pores, converting it into peroxide and liberating the acid once more. At the same time hydrogen is brought to each negative plate and acts on the sulphate of lead in its pores, converting

it into spongy lead and sulphuric acid. Thus the effect of a charging current is to bring back the active materials to their initial state, and to restore the acid to its original strength. At the end of a complete charge the cell is therefore ready for a fresh discharge, and may for many purposes be regarded as a new cell. This constitutes one of its greatest advantages, for it is much more convenient to recharge in this way than to perform the manual labour of getting and installing new plates, etc. To recharge a Daniell cell the old zinc plate must be replaced by a new one, the liquids must be thrown away and a fresh lot inserted after washing, and the connections re-made—a set of operations much more troublesome than the mere switching on of accumulators to a dynamo to be recharged.

There is an erroneous idea that the "charging" of an accumulator results in its having more electricity than before, and that this extra electricity is given out during the subsequent discharge. This idea is proved to be false by the fact so often stated, namely, that a current cannot be passed *into* an accumulator, or, indeed, into anything. It can be passed *through,* but this means that as much comes out as goes in. As soon as that is recognised the idea of charging a cell *with electricity* vanishes. What the charging current does is to make a quantity of new chemicals (peroxide and spongy lead with free acid), and these chemicals are capable of putting into circulation the electricity in a circuit of which they form part.

Signs of Complete Recharging.—The completion of the charging operation is known by several signs. (*a*) The colour of the plate is fully restored: the positive is a rich dark brown, the negative a light blue colour. (*b*) The density of the acid is brought back to its higher value, 1,210. (*c*) The pressure of the

cell is considerably above 2 volts, and may be 2·5 at the end. (*d*) Copious streams of gas bubbles are given off by both plates; oxygen at one, hydrogen at the other. These bubbles appear at first in small quantity, but more plentifully as the charging approaches completion. Indeed, they then mix with the whole liquid and make it look quite milky. The gases appear at the end because there is no more sulphate of lead on the plates for them to act on.

Charging Voltage.—It is noteworthy that during charging the electric pressure of the cells is higher

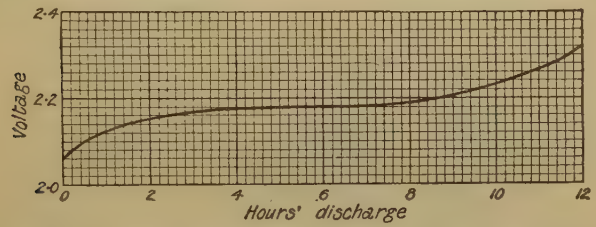


Fig. 97.—Curves showing rise of pressure during "charge."

than that given in the discharge, and at the finish rises to 2·5 volts. Fig. 97 shows the way in which it varies. This higher voltage is caused by the active materials having stronger acid in their pores. As we have explained, the charging operation restores acid to the liquid. This acid, being derived from sulphate of lead hidden in the spongy masses of the discharged cell, is liberated in the porous recesses, and makes the acid there stronger than that outside. This temporary rise in acid is the cause of the higher pressure.

At the end of the charge the pressure has still the abnormal high value seen in Fig. 97, and if the charging current be then stopped this voltage slowly sinks for about half an hour, falling from 2·3 to 2·0 volts.

CHAPTER VIII

ELECTRIC BELLS

An electric bell is a very simple matter, though in complex cases much experience is required.

Single-stroke Bell.—Fig. 98 gives the arrangement of a single-stroke bell. The bell consists of an electromagnet, which is excited only when the current

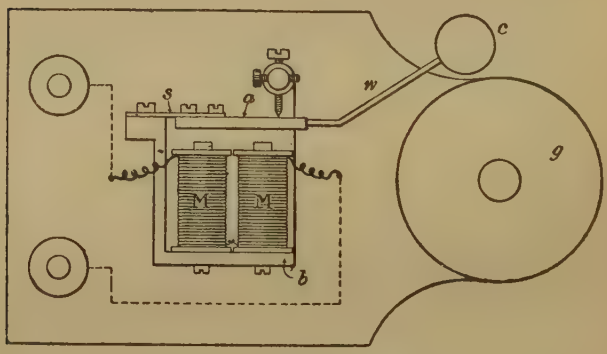


Fig. 98.—Single-stroke bell.

flows. There are two magnetising coils M M, each having an iron core running through, screwed to the iron base *b*. Above the cores is a small iron bar armature *a*, to be attracted by the magnet. This armature is carried by a thin spring *s*, which keeps the whole in position against an adjustable screw, by which the distance between armature and iron cores can be regulated.

At the other end the armature is attached to a stiff wire *w*, at the end of which is the clapper *c*. When electricity flows through the coils M M the cores are magnetised, and the armature *a* is pulled down smartly, thus carrying the clapper *c* against the bell-gong *g*. When the current ceases the magnetisation vanishes, and the spring *s* pulls the armature back to the position shown in Fig. 98.

The foregoing is called a single-stroke bell, because it gives only one stroke when the push is pressed down. Even though the pressure is continued, and the circuit thus kept closed for many minutes, there is only one stroke: the clapper is held down against the gong.

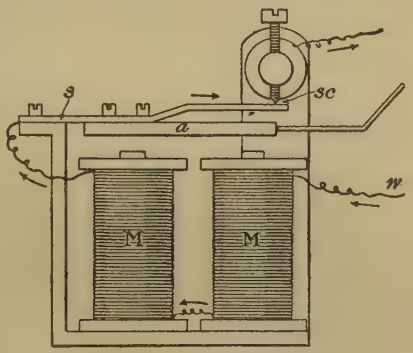


Fig. 99.—"Trembler" bell.

The stroke is given at the moment when the push completes the circuit, and if it be unobserved there is nothing in the arrangement to attract attention. For this reason the single-stroke bell is largely replaced by the trembler bell.

Trembler Bell.—This has an automatic device for breaking the circuit as soon as the bell is struck, and if the push be still down a continuous ringing is produced. Fig. 99 shows the bell; the gong and the end of the wire carrying the clapper are omitted. The general arrangement is similar to that of the single-stroke bell: the difference lies chiefly in the flat spring *s* by which

the armature *a* is brought back. In the trembler bell this spring *s* is continued and bent upward, so as to touch a screw *sc*. The automatic break of the circuit depends on the current being made to pass through *s*, so that the contact between *s* and *sc* becomes a necessary part of the circuit.

Current enters the bell by a terminal attached to the wire *w*, and passes through the coils M M to the spring *s*. From this it flows to the screw contact *sc*, and thence to the second terminal. When the push is pressed a current flows, and the following sequence of events occurs :—

(*a*) The magnets are excited and attract the iron armature, giving a stroke on the bell. (*b*) The movement of the armature drags the spring *s* away from *sc*, and thus breaks the circuit. (*c*) The current at once ceases, the magnetism disappears, and the flat spring *s* restores the armature. This re-establishes contact between *s* and *sc*. (*d*) The current flows once more, and the cycle is repeated as long as the push is held down.

These events take place so rapidly that many strokes of the clapper are produced even though the push is held down for a few seconds only. In fact, the clapper is kept in a state of rapid movement or trembling—hence the name, Trembler bell.

Two points are of importance for the satisfactory working of the bell. First, the contacts at *sc* and *s* ought to be made of platinum, for a spark occurs at each break there, and there is a strong tendency to melt and corrode any ordinary metal. Platinum does not melt or corrode, so that a small, flat bit of platinum foil is fixed on *s*, and the end of the screw contact *sc* is extended by a small platinum rod. The second point is, that when the armature is attracted by the magnets

it ought not to touch the poles. If it should touch it is very apt to stick, and so throw the bell out of order. When a bell shows any tendency for its armature to stick, a bit of thin writing-paper placed on the top of the poles will prevent it. The explanation is simple. To get a good trembler action, the iron cores must be very ready not only to take the magnetic state when the current flows, but also to yield it up as soon as the current ceases. Now, good soft iron will do this, but only on condition that its poles are not connected by iron. A crossbar which touches gets almost as highly magnetised as the iron cores, and it reacts on them, tending to retain the magnetism, although the current may have ceased. Iron arranged in this way forms a magnetic circuit and is slow to give up its attractive powers. Hence the sticking. A little bit of thin paper prevents the contact and leaves a gap between the cores and the armature, even when the latter is dragged down.

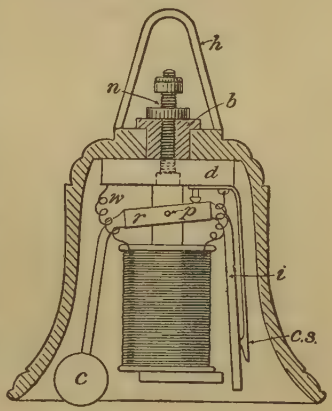


Fig. 100.—Jensen bell.

Jensen Bell.—This is a bell in which the magnet and clapper are enclosed in a gong of the type shown in Fig. 100. The fact of enclosure allows it to be used in exposed positions, and the shape of the gong yields sounds of different tones from those of ordinary bells. The magnet coil excites the core in the usual way, the core being provided with one or two pole pieces. In

the figure only one is shown. The moving part consists of the clapper *c*, attached by a rod to the ring *r*, pivoted at *p*. On the other side of the ring is the iron arm *i*. Normally, this is touched by the contact spring *c.s.*; *b* is an insulating bush, and *d* is a wooden support for *c.s.* The gong itself is one terminal and the central rod and the nut *n* forms the other. The current flows in by the suspending hook or swivel *h* and through the gong to the wire *w*. From this it passes to the coil, and then by a second wire to the screw which secures the bent contact spring to the wooden block *d*. It now flows through *c.s.* and *i* into the ring *r*, and then through the pivot to the nut *n*, and so back to the battery.

A simple circuit of bell, battery, push, and line suffices to call attention in the case where only one point is in question. In an ordinary house, however, there may be several points of call—four or six pushes in different rooms are quite common—and in these cases it becomes necessary to have an index or indicator which shall show which room is calling.

The method adopted is to make the circuit for each push practically independent and to arrange for it to work an additional electromagnetic device. We shall first describe the general arrangement of an indicator circuit, and then show two of the many forms of indicator.

Simple Bell Installation.—Fig. 101 is a diagram of the way in which a simple installation without indicator is arranged. The battery consists of two Leclanché cells L L, the bell B is like that of Fig. 99, and there are three pushes—one F.D. at the front door, another D.R. in the dining-room, a third B.R. in a bedroom.

The three pushes are arranged in parallel, that is to

say, each push can independently complete a circuit when it is pressed, and so enable the bell to ring. If one push is pressed the wires leading to the other pushes have no current in them. To make this clear, arrows are drawn to show the course of the current when the dining-room push D.R. is pressed.

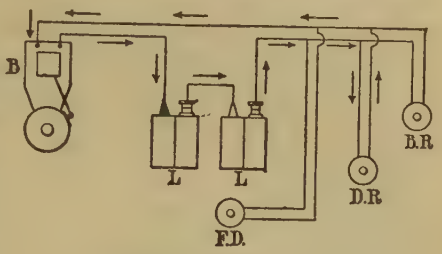


Fig. 101.—Simple bell circuit.

With an arrangement like that of Fig. 101 there is nothing to tell which of the three pushes is calling when the bell rings. The sound of the bell is the same for all three.

Fig. 102 shows the same circuit with an indicator. L L is the battery, B is the bell, and F.D., D.R., and B.R. are the pushes, as before. The addition consists of three electromagnets, one in the circuit of each push, and all in series with the bell. When any one push is pressed the bell will ring and the indicator magnet belonging to that push will act. To make this clear the indicator magnets are marked by the same letters as the pushes. Small arrows show the course of the current when the dining-room push is pressed. The

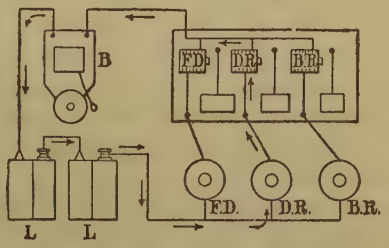


Fig. 102.—Bell and indicator circuit.

method by which the indicator reveals the origin of the call depends on the movement provided. In the most common form the indicator magnet simply attracts an armature hanging like a pendulum, as is suggested in Fig. 102. The attractive force of the magnet drags it out of its vertical line, and when the force ceases it falls back again, but vibrates for a long time before it remains at rest. Thus, by noticing which indicator is in motion, the locality of the push is known.

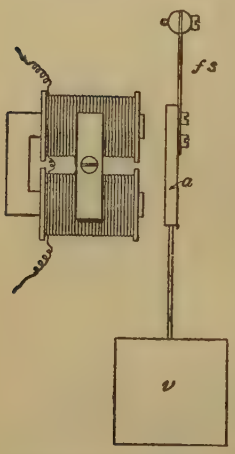


Fig. 103.—Pendulum indicator.

Fig. 103 gives some details. The thin flat spring *f s* carries the armature *a* and also a vane *v* (which is seen at a window in the front of the indicator box). As soon as the magnet has attracted *a* the vane *v* is seen to be oscillating right and left behind the window. We shall have something more to say about this indicator a little later.

Another form of indicator movement is shown in Fig. 104. The magnet has a simple straight core. The iron armature *a* is fixed to one end of a lever, pivoted at *r*, the end having two projections which serve as a catch *c*.

Pivoted at *p* is a second lever, whose upper end carries a red disc *d* and an arm *e* (behind the disc), which engages in the catch of the upper lever. This second lever is made so that the upper end is considerably heavier than the lower, with the consequence that the former tends to fall. In fact, as soon as the catch is removed, the disc tilts forward into the dotted

position and becomes visible at its window in the front of the indicator box.

The work of releasing the catch is done by the current. This excites the magnet, which pulls down the armature and tilts the top lever into the dotted position, where, of course, the catch is no longer able to restrain the disc from falling.

It will be observed that it is necessary to replace this disc before it can respond to a second signal. This is done by a rod R, which slides inside the indicator box and at one end projects outside, terminating in a knob. The rod R is provided with studs *s*, which rise about $\frac{1}{8}$ or $\frac{1}{4}$ inch above its front surface. Suppose now that the disc lever wants replacing; it lies in the dotted position. The rod R is pushed to the left, its stud *s* presses on the lower end of the lever and carries it to the upright position, where it is held by the catch *c* and where it is ready for another call. Of course the rod R carries a stud like *s* for every disc there is in the indicator box. In other respects the movements and connections are arranged according to the plan of Fig. 102.

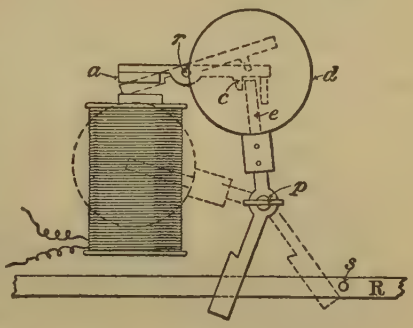


Fig. 104.—"Drop" indicator.

The indicator movement just described belongs to the class known as indicators with mechanical replacement. It therefore depends on the action of those who

are called by it. Experience shows that careless servants do not always replace the movement for further use, and in so far all forms of mechanical replacement have a slight disadvantage. The competing forms are either those like the pendulum movement, which do not require replacement, or certain other forms working by "electric replacement." An example of this last method is shown in Fig. 105.

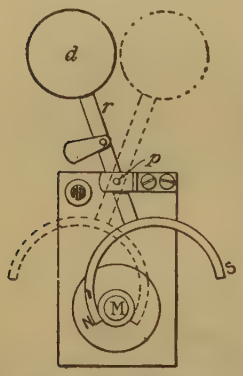


Fig. 105.—Indicator with electric replacement. (*Spon.*)

A rod *r*, pivoted at *p*, carries a disc *d* at its upper end and a curved steel permanent magnet N S at the other. Fixed on the same upright support as that which carries the pivot *p* is a straight electromagnet M. In the diagram the pole only is seen. The core of this electromagnet is wound with two coils of wire, and these are connected so that the current flows in them in opposite directions. These coils are connected to the battery by different circuits, one being the ordinary circuit for calling, the other a mere replacement circuit.

Suppose a call reaches the bell and indicator. The current magnetises the iron core with north polarity at M. As like poles repel, the N pole of the steel magnet is at once pushed away, while S is attracted. These forces throw the movement over into the dotted position, where the disc can be seen.

To replace the disc the second push must be pressed, so as to get a current round the second coil. As this flows round the core in a reverse sense, S polarity is induced at M and the like pole of N S is

repelled; the lever, with its disc, is brought back to the original position, as shown in full line.

Relay.—There are cases where it is not advisable to use an ordinary bell directly. For example, where a pendulum indicator is employed as suggested in Fig. 102 the movement of the bell trembler gives rise to a series of magnetisations which may easily occur at the wrong moment. The current may give a second

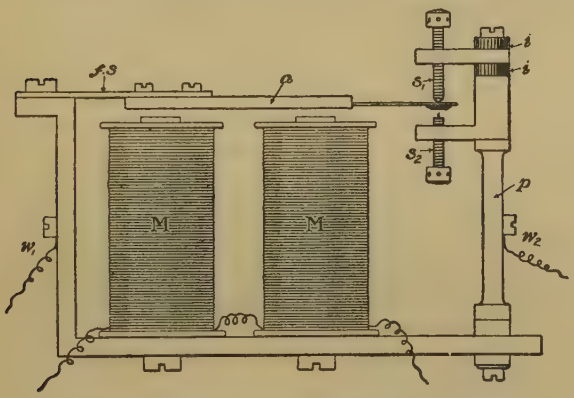


Fig. 106.—Relay for pendulum indicator circuits or for long lines.

attraction to the pendulum just when it is about to swing back, and its motion may be stopped instead of assisted.

This interference of the vibrating armature of the bell with the vibrating pendulum is apt to diminish the value of the method, but the difficulty is avoided by putting a relay in place of the bell. The relay is like a single-stroke bell in some respects and like a push in others. It is wanted to act as a key for the purpose of closing a local circuit, in which a trembling bell can be arranged to work. Fig. 106 explains the mechanism:

M M are the magnets receiving the current from the line when the distant push is pressed. They take the place of the ordinary bell magnets. When excited they drag down the armature *a*, which is to act as a key for a local circuit. Consider the wires w_1 w_2. These have no connection with the coils M M, or with the line in which the magnets are placed. One of the wires, w_1, goes to a cell, and through it and a bell is connected to w_2. Notice, however, that this local circuit is incomplete, for w_2 is insulated from w_1. In the diagram w_1 is connected through the framework to the flat spring *f s*, and through the armature, etc., to the set-screw s_1. On the other hand, w_2 is joined to the post *p* and to the set-screw s_2. But s_1 and s_2 are not connected, for s_1 is supported by insulating washers *i i*. Hence there is no circuit for w_1 w_2 till the armature *a* is attracted and its end is brought down on s_2. As soon as that happens the local circuit is complete and its bell rings. The trembling of such a bell will, of course, have no action on the relay, and this keeps its contact as long as the distant push is pressed home.

A relay of this kind is often introduced in cases of long lines. The extra length of line means extra resistance and diminished current, and an appreciable weakening of the current may make it unable to ring a bell with sufficient vigour. The same weak current can, however, easily attract the armature of the relay, for this can be specially wound with thin wire and many turns, so as to respond to weak currents.

Alarm Bells.—Electric bells are often used as alarms, for burglars, fire, and other purposes. It is obvious that a key or push can be inserted in the sash of a window or the jamb of a door in such a way as to close a circuit when the one is

raised or the other opened. Fig. 107 shows the contact adopted in the case of a burglar alarm or door-contact. When the door (or window) is closed it presses on the ball, and so keeps the spring *s* away from the insulated brass plate *b*. When the door opens the spring *s* presses the ball in and, making contact with *b*, completes the circuit and rings the alarm.

It is evident that such an alarm push is not sufficient for all cases. A smart burglar will speedily stop a bell which has started ringing by cutting wires, etc., and this may be done before anybody has been roused

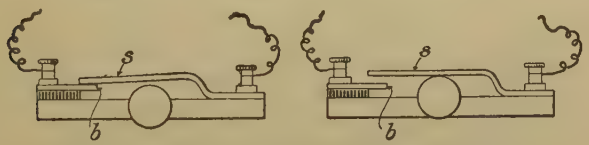


Fig. 107.—Window or door alarm, closed and open.

by the noise. A useful modification is therefore introduced in the form of a *continuous-ringing bell*. The special feature of this lies in the fact that, once started by the alarm contact, it becomes independent of the circuit. Even though the original conductors be cut, it goes on ringing till stopped by resetting. A bell of this kind, placed, say, in a bedroom, will ring till the sleeper awake or the battery be exhausted.

Continuous-ringing Bell.—This is a trembler bell with the addition of an extra contact. From Fig. 108 it will be seen that there are three terminals, T_1, T_2, T_3, and that the armature of the trembler is bent back at the point *a*, where it serves as a catch to hold up the lever *l*. When the alarm-push in window or door makes contact, the current flows through the coils

of the electromagnet, excites the cores, and pulls the armature to the left. This at once releases the lever *l*, so that the spring *s* pulls it into contact with the screw *w*, as shown by the dotted line. This contact now makes a circuit for the local bell and battery which is quite independent of the original push. To make this clear, a small diagram of connections is shown above the bell: *c* and *x* are the terminals of a battery; *c* is joined to the bell terminal T_1; *x* is joined to the alarm push *p* and through it to the middle bell terminal T_2. These complete the *alarm circuit* proper. When the opening of door or window closes *p*, a current will flow from *c* through the electromagnet coils into the vibrator spring *v.s.* and contact post *c.s.*, and so out by T_2 through the push back to *x*.

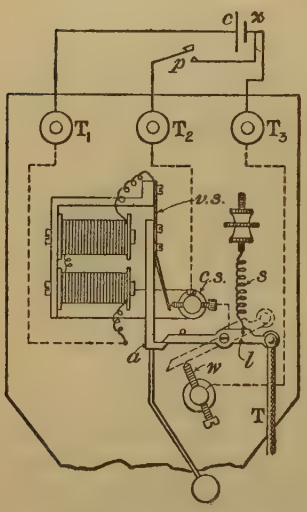


Fig. 108.—Continuous-ringing bell. (*Spon.*)

The bell begins to ring, and brings in the second circuit. To provide for this the battery terminal *x* is also connected to the third bell terminal T_3, and therefore, as shown by the dotted outline, to the screw *w*. Consequently when the first move of the armature releases *l*, the latter falls on *w* and makes contact with *x*, setting up a fresh line of flow. The current now passes from *c* through the coils and vibrator spring into the contact post *c.s.*, from it into the lever *l* and

screw w, thence back to T_3 and x. This auxiliary circuit renders the bell independent of the push, and it rings till someone pulls back the lever l. The rope T is used for this purpose.

Another way to get a continuous-ringing bell is to arrange an ordinary trembler in conjunction with a relay (Fig. 109). The relay terminal T_1 is connected to the carbon of a battery, T_2 to the alarm contact in window or door, and thence to the zinc. When this alarm contact is made the relay magnet M is excited and pulls over its armature a, so that the lever l is brought into contact with c. In this way a second circuit is completed, for t_1 and t_2 are connected to a trembler bell, while T_3 is connected to the zinc end of the battery. Consequently an alarm current now comes to T_1, then through w, etc. (as shown by the arrow), to t_1, through the bell and t_2, c, and l back to T_3 and the battery.

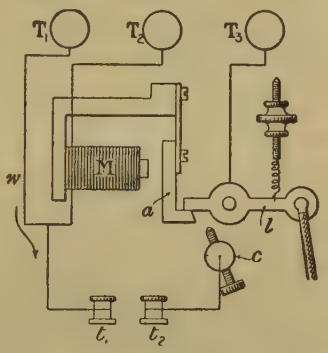


Fig. 109.—Relay arranged for continuous ringing of alarm bell.

Closed Circuit Bell.—There remains a final difficulty in respect of alarms. A clever burglar may be able to cut the wires of a bell circuit before the alarm push has come into action. In that case there can be no alarm. It is possible, however, to deal with this contingency by arranging a bell so that it rings when the circuit is broken, but keeps quiet as long as the circuit is complete. The bell is arranged with three

terminals, and is joined up to battery and line, etc., as shown in Fig. 110. Any alarm push at the window, etc., such as A.P., must be arranged so that the circuit is closed as long as things are right, but opens the contact if things go wrong. The effect of this is that when the apparatus is set for the night, by closing the switch S, a current flows through the line and magnets, holding down the armature *as long as the circuit is intact.* Hence the bell cannot ring. It is a single-stroke bell, giving a stroke at the moment of setting and then remaining down. But as soon as the line is broken the armature springs back and makes contact by its bent spring with the contact screw; the bell becomes a "trembler," and continues ringing till attention is given. The switch S is open during the day, so that the battery cannot act.

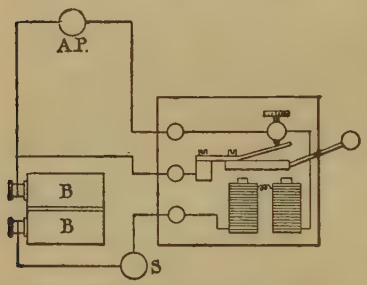


Fig. 110.—Closed circuit bell.

An arrangement of this sort makes larger demands on the battery than a simple Leclanché is capable of supplying; some other form of cell is therefore adopted.

Fire Alarms.—These depend on the fact that heat causes expansion, and that it is possible for an expanding substance to make a contact.

One form is in the shape of a thermometer (Fig. 111*a*). A wire leads into the bulb at the bottom, and is in contact with the mercury. A second wire passes through the upper end, leaving a gap between itself and the mercury column below. As the tempera-

ture rises the mercury expands and at a certain point will touch the upper wire and complete the circuit, thus ringing the alarm bell. Evidently the temperature at which contact shall be made can be arranged by adjusting the position of the upper wire.

A second form depends on the fact that a strip

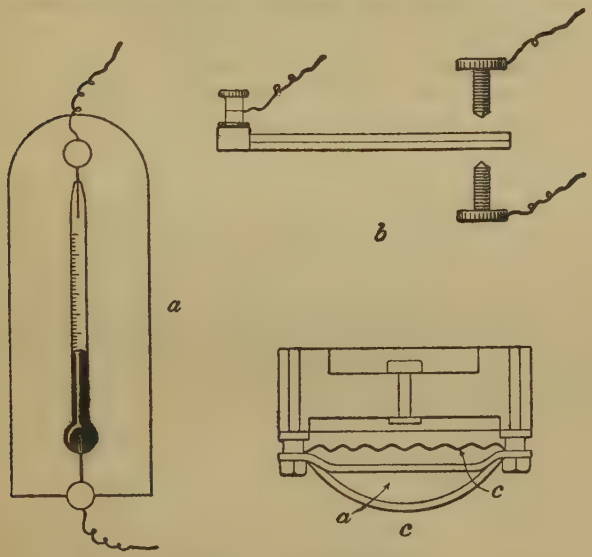


Fig. 111.—Fire alarms

built up of two thin metals bends when it is warmed or cooled. It can thus be made to indicate high or low temperatures. The bending depends on the different rates at which the metals expand. Zinc, for example, expands at twice the rate of iron. A strip made up of equal lengths of these may be perfectly flat at the ordinary temperature. When warmed the zinc expands most, and gets longer than the iron. As

they are firmly united together they can allow for the greater length in one way only, and that is by curling, with the zinc on the outside of the bend.

In Fig. 111*b* the compound strip is shown between two stops. On warming, the free end curls up and touches the upper stop, completes the circuit, rings the bell, and so gives warning of a high temperature. If subjected to very low temperatures the strip curls downwards and touches the lower stop, ringing the bell as in the other case. The set-screws allow of adjustment, so that the alarm will be given for different temperatures.

A third form (Fig. 111*c*) depends on the expansion of air. A thin-walled chamber *a* is covered with an air-tight corrugated metal *c*. As the air warms it expands, and presses *c* upwards until it touches the screw above it. This screw and *c* are in contact with the wires of a bell circuit, and thus make contact and ring a bell when the temperature rises to a definite value.

CHAPTER IX

TELEGRAPHY AND TELEPHONY

Telegraphy.— The name telegraphy is now applied to any electric system by which communication is established between distant stations, it being understood that the message is conveyed by means of symbols or signs. When actual speech is transmitted the name telegraphy gives place to telephony. The methods used are now very numerous, but they all agree in requiring very weak currents. Economy demands that the currents shall be weak, for strong currents on such long lines would mean a great loss of power in the wire. Moreover, it is usual in telegraphy to use the earth as a "return" conductor, and this would be very inconvenient if the currents employed were very large.

Batteries Employed.—The batteries now used in telegraphy are the Daniell, the Leclanché, the Fuller's mercury-bichromate, and the accumulator. These have already been described with the exception of the Fuller, and it will suffice for our purpose to say that this is a zinc-carbon cell, and consists of a porous pot containing dilute sulphuric acid and the zinc rod, an outer earthenware jar containing a solution of bichromate of potash in dilute sulphuric acid. A small quantity of mercury is placed at the bottom of the porous pot, and in this the zinc rod stands; the latter is kept well amalgamated in this way. The bichromate of potash is rich in oxygen and acts as a depolariser; it takes the place of the manganese dioxide in a

Leclanché cell or the peroxide of lead in an accumulator. The electromotive force is just above 2 volts.

It may be taken for granted that the most usual forms of cell in small stations are the Daniell and the Leclanché. In large stations the accumulator is replacing every other kind.

Telegraphic Circuits—Earth Return.—The general idea of a telegraphic *circuit* is shown in Fig. 112.

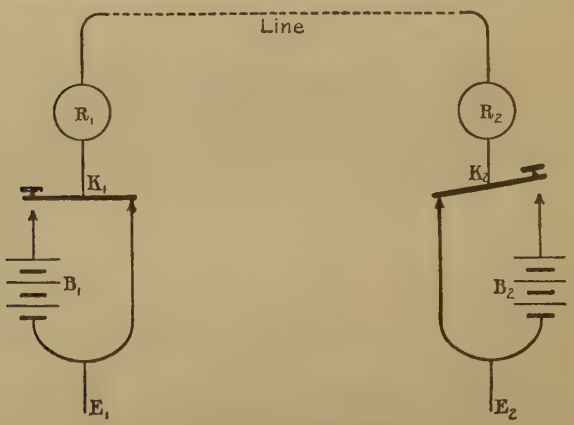


Fig. 112.—Simple telegraphic circuit.

It is arranged with two batteries, one at each end; each station can send a current by putting down its key. Let K_1 be put down. The circuit is then easily followed. We may start with that pole of the battery B_1 which is connected to the key K_1, and proceed by the line to the other station and through the back contact of its key K_2 to earth E_2. From this the current flows by all possible routes to E_1, and thence through the battery B_1 to the point from which we started.

R_1 R_2 represent the two receiving instruments: their

method of producing signals will be given presently. For the moment consider the "earth return." The crust of the earth is made of materials whose electric conductivity is very low, and at a first glance the "earth return" does not seem very promising. But the conductivity between two points in the earth is really very good, because of the enormous size of the path through which the electricity can flow. In going from earth-plate at one station A to that at another station B, the current spreads out over very large regions, and so passes most easily. It is sometimes asked: "How does the electricity know where to go, and why do not the different currents get mixed up?"

This is a misleading question. When electricity enters the earth at E_2 other electricity passes from the earth into the wire at E_1, but *it is not the same electricity*. The case is similar to that of a pump which pumps water through a long pipe into the sea, say, at the other side of the Atlantic, and which has its service or entering end joined by another pipe to the same water near at hand. Every stroke of the pump would force water out at the other end and take it in at the near end. The water in the sea would itself make the necessary adjustments of level.

The Line Wire.—This generally consists of the best iron wire, and varies in size according to the length of circuit. For ordinary circuits its diameter is about $\frac{1}{8}$ of an inch, weighing about 200 lbs. per mile. For longer lines it may be twice as much, having a diameter about $\frac{1}{6}$ of an inch.

The Insulators.—These are made of good porcelain, whose surface has been covered with a glaze that will not allow moisture to get into its pores. Fig. 113 shows the form they commonly take, the object being to reduce leakage to a minimum. Each insulator is a

kind of inverted double cup, and is known as a double-shed. An iron bolt runs up the central cup, and is fastened in a suitable recess. It was formerly the practice to cement the rod into the inner cup, and this again into the outer one, but the screw method adopted in the second figure is now much more in favour, as it is easier to replace. In the screw form an elastic washer is placed between the insulator and a shoulder formed on the iron rod. The third figure shows

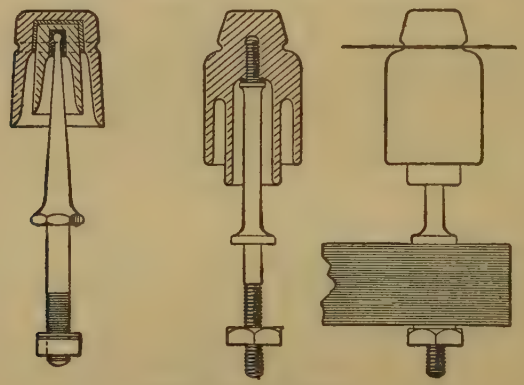


Fig. 113.—Insulators.

the method of binding the line wire in the groove of the insulator. The iron rods are of course fastened on the arms which project from the top of the poles.

The reason for designing the insulator in the shape indicated is fairly obvious. As the earth forms part of the circuit there is a tendency for the current to leak through to earth at every insulator, a tendency which is increased by a shower of rain. Now the outer cup forms a shed over the inner one, and shields the inner one more or less, so keeping it fairly dry. Moreover, the form adopted makes the leakage path

more difficult by increasing its length. Any leakage must flow down the outside of the outer cup, then up its inside surface. Even then there remains the flow down and up the inner cup before the iron rod and cross arm are reached, thus making a great obstacle to leakage. Nevertheless, so many of these insulators are used in a long line that the total leak may become appreciable, especially in wet weather.

Instruments.—The principal receiving instruments now used are the Needle, the Sounder, the Bell, and the Morse Recorder. Besides these, the A.B.C. system is used on private or short lines where speed is not so important. A short account of the typical ones will be followed by a few words on printing and automatic methods.

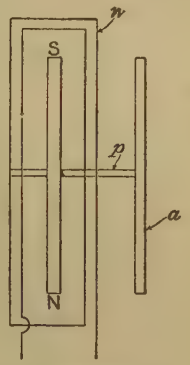


Fig. 114—Diagram of needle instrument.

The Needle Instrument.—This depends on the ability of an electrical current to deflect a magnetic needle (*see* page 17). Fig. 114 is a diagram of the arrangement; Fig. 115 shows the front of one form of instrument. The magnetised needle N S stands vertically, being slightly heavier at the lower end. It moves on a horizontal pivot *p*, and is surrounded by a coil of wire *w*. A dummy needle *a* is fixed at the front, and moves on the same pivot as N S; by this means the movement of the inner needle is shown to the operator. When a current flows through the coil its magnetic field (*see* page 9) pushes the poles N and S in different directions. One of them, say N, will be driven towards and the other, S, away from the reader. Viewed from the front, the upper end would move to the left, and

N

this is the point observed. If the current be reversed the upper end of the needle moves to the right. By appropriate combination of right and left movements the words are spelled out to the receiving clerk.

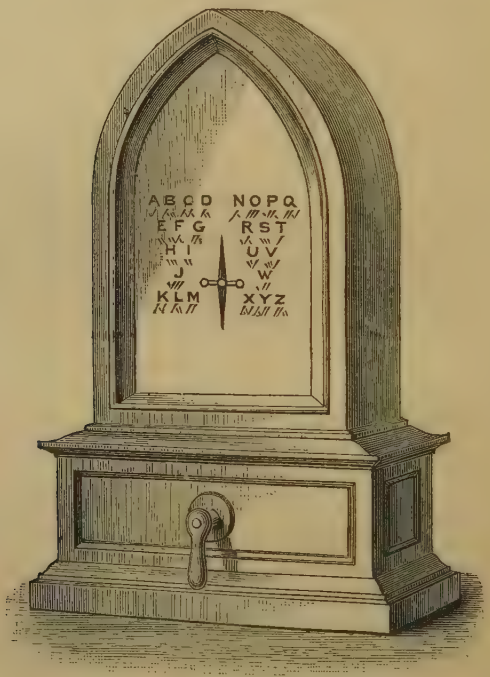


Fig. 115.—View of needle instrument.

The method of making the reversed signals depends on a double-tapping key or on the right and left motion of a drop-handle. A plan of the tapping key is seen in Fig. 116. The tappers L and E consist of brass springs, screwed down to a base at the back and pressing upwards against a metallic bridge z near the

middle. Under the handles h_1 h_2 is a brass plate C, which is joined to the positive end of a battery. The bridge Z is joined to the negative end of the same battery.

Normally both springs touch Z, and thus connect the line wire w to earth E. A current can therefore come from the distant station, pass through the receiving needle instrument to L and thence by Z and E to earth.

When the operator presses down h_1 L is joined to

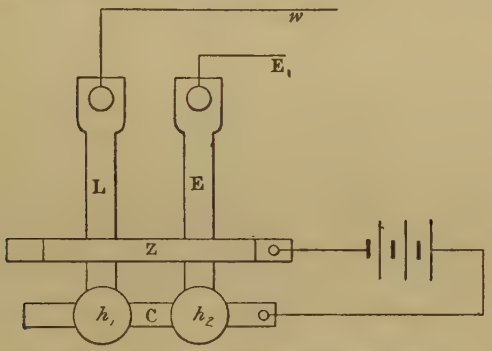


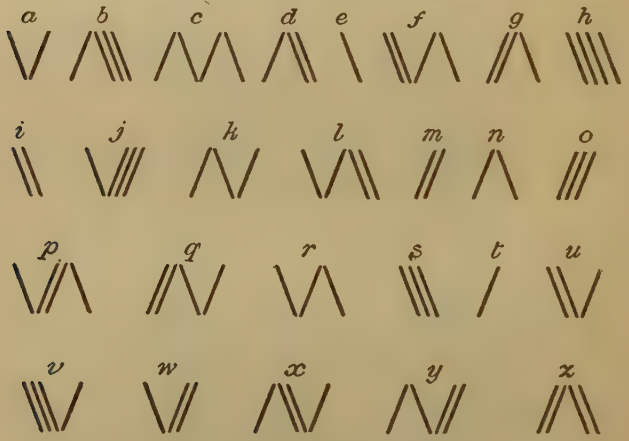
Fig. 116.—Tapper for needle instrument.

the positive end of the battery; a current flows to line, comes back through earth E to Z, and so to the negative end of the battery.

When h_2 is pressed down the earth E is joined to the positive end of the battery; a current flows through to the distant station, then through its receiving instrument and along the line to L, and so by Z to the negative terminal. It is evident that this current is flowing in a reverse direction to that which followed the pressing down of h_1 and that the needle of the receiver will move in an opposite way.

The drop-handle form of key works on the same principle. When moved to the right it connects line and positive; when to the left it joins line and negative; in each case the proper earth connection being also established.

The Code of Signals.—The motion of the needle to right and left is arranged to represent letters according to the following scheme. The slope of the lines



Code of signals.

represents the movement of the needle; a stroke / represents a move to the right, a stroke \ represents a move to the left. Thus *a* is one stroke left, one right; *h* is four left; *q* is two right, one left, one right; and so on.

Other systems have been used, but the above is now almost universal. It is the same as the Morse code for the sounder, a dot in one and a "left" signal in the other being equivalent, as also are a dash and a "right" signal.

Tin Sounder.—In some forms of needle instrument the instrument is converted into a sounder by placing a tube of tin plate *t t* on either side (Fig. 117). The movement of the needle brings it in contact with one or other of these tubes (or a pin attached to them), and so produces a sound. It is easy to make the sound different for the right and left signals, and hence to be able to read without looking at the needle.

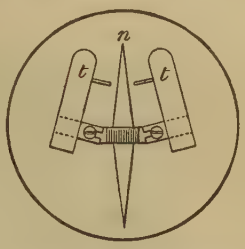


Fig. 117.—Tin sounder attached to needle instrument.

The Sounder.—In this instrument the current excites an electromagnet and draws down an iron armature. This motion is used to produce a sound, and by making long or short signals a code is obtained which is readable by ear.

Fig. 118 is a rough diagram of the arrangement. When the current passes through the coil c its iron core *i* is magnetised, and the iron armature *a* is drawn

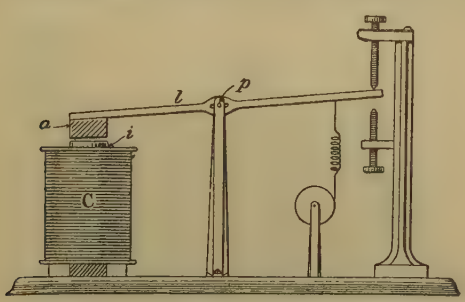


Fig. 118.—Diagram of Morse sounder.

down. As the armature is fixed on the end of a lever *l*, pivoted at *p*, the farther end of *l* is moved quickly from

the lower stop into smart contact with the upper one, thus giving an audible signal. The lever is shown in

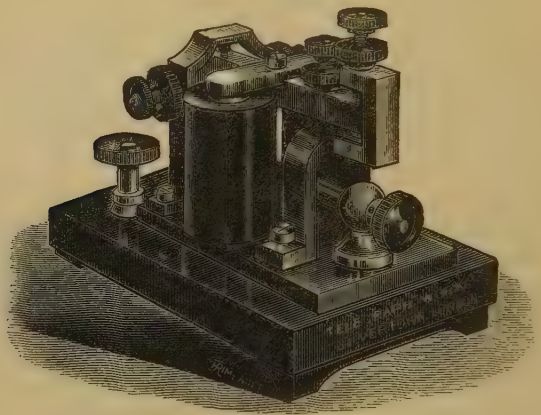


Fig. 119.—The Post Office sounder.

this position. When the current ceases the magnetic attraction vanishes, and the spring pulls the armature lever back ready for the next signal.

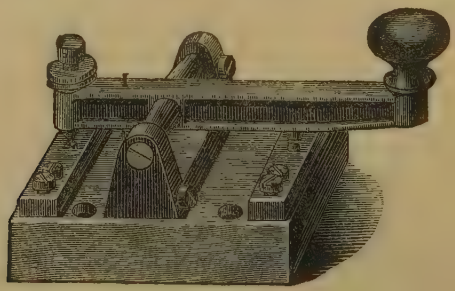
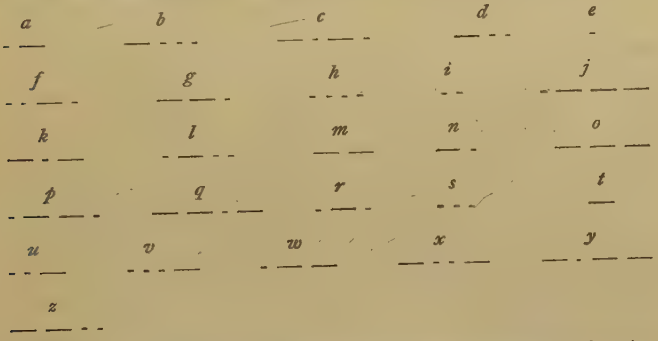


Fig. 120.—The Morse key.

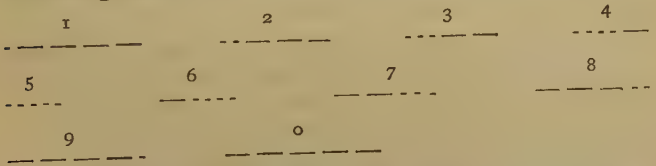
Fig. 119 shows the compact form which this instrument now takes, and Fig. 120 shows the key by which

the long and short signals are made. There are three terminals: one at the back for the back contact, one for the middle of the key, the third for the front contact. When not in use a spiral spring pulls the back of the key down, so that the contacts at the middle and back of the key are joined together. When the front of the key is pressed down the back contact is broken and the middle and front contacts are joined together.

The code is made of long and short sounds, and may be written as follows:—



Figures are represented by five signals arranged in the following way:—



A modification of the Morse sounder is known as the ink-writer. The armature lever carries at its far end a little wheel kept rotating by clockwork. This dips partially into an ink well. When the armature is pulled down the ink wheel is carried upwards into

contact with a moving paper tape. The ink-writer is now little used.

Relays.—On long lines the signals are often very weak, partly because of leakage at the many insulators and partly because the line wire has a very considerable resistance, and therefore does not allow a strong current to be established. The value of the current flowing from the battery can be increased by using more battery cells (a higher electric pressure), but this increases the leakage, and is a quite inadequate plan.

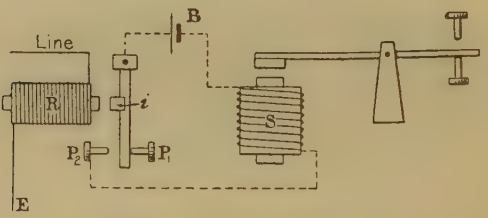


Fig. 121.—Relay working.

The method adopted is much better. A *relay* is employed, by which the feeble currents which arrive are used to bring in a local battery.

Fig. 121 shows the plan of working. The line wire is connected, not to the sounder S, but through a coil R to earth. When a signal comes from a distant station it magnetises the iron core of R and attracts the armature *i*. The lever is therefore pulled away from the stop P_1 and brought down sharp on P_2. The moment this is done, the *local* or auxiliary circuit shown by the dotted line is closed and the *local battery* B is able to send a strong current through the sounder S and thus give the signal. Every signal, therefore, which arrives at R at once reproduces itself on S.

It may be asked: Where is the advantage of the

arrangement? If the arriving current will work R, why cannot it work S? The reason lies in the fact that R can be made much more sensitive than S. The sounder must give a decided signal, and requires a certain definite pull on its armature. The relay can be made to work much more gently. Its coils can also be wound with finer wire and more turns, thus enabling the weak current to have a larger magnetising effect. Other forms can also be adopted for the relay; indeed, the most usual type is a polarised relay whose action may be followed in Fig. 122. This is a plan showing the top ends of an electromagnet whose cores are provided with adjustable pole pieces P_1 P_2. On the right side is one pole *s s* of a permanent steel magnet, which runs down and bends under the iron cores of the electromagnet. Pivoted in a slot at *b* is a *light* armature of soft iron *b a*, having a tongue of German silver *g* fixed to it. The free end of this tongue can play between two stops s_1 s_2.

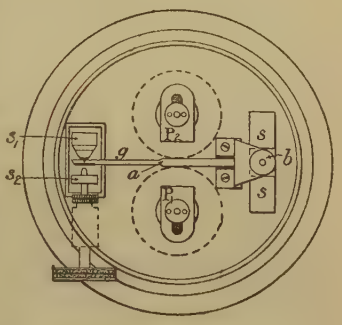


Fig. 122.—Siemens' polarised relay.

The net result of the arrangement is that the steel magnet induces magnetic polarity in the armature *a b* and in the electromagnet cores P_1 P_2; *b* is a north pole, *a* is south; P_1 P_2 are *both* north poles; *a* is therefore attracted by both P_1 P_2, but as P_2 is placed nearer its attraction is greater, and *a* is brought up against the stop s_1. When the current arrives it passes round the

coils in such a way as to strengthen the north pole P_1 and weaken P_2. Hence the armature is brought over towards P_2, and the tongue g touches s_2. This completes the local circuit and makes the signal.

The adjustments of the Siemens' relay make it a very sensitive instrument, and enable telegraphic work to be carried on in trying conditions; but it is not so sensitive as some other forms. The Post Office standard relay, sometimes called a *repeater,* is much more sensitive.

Automatic Telegraphy.—Wheatstone's automatic telegraph instrument is an exceedingly ingenious device for sending the signals by machinery. It was designed originally to increase the speed of signalling, and proved very successful. An operator working a key cannot put down the key for a series of dots and dashes at a greater rate than 200 letters in a minute. His muscular activity does not allow of up-and-down movements being made more frequently. But there is no such limitation for a machine. A small lever can be made to touch a contact and to make dots and dashes at a much greater speed. This possibility is admirably worked out in Wheatstone's automatic contrivance. Only a brief reference can be given here.

The first operation is to punch a paper tape with holes, one set for dots, another for dashes. This tape is then sent through a transmitter, in which two levers are moving up and down with immense rapidity. As long as they meet the unbroken paper they do nothing but vibrate, but when they come to the punched holes they pass through and make contact one after the other. The one sends a *marking* current to line, the other takes it off. For a dot the second "takes off" almost immediately after the first "puts on." For a dash a longer time elapses. The speed can be adjusted by

means of clockwork and a regulating fly or governor. The maximum speed is about 500 words per minute. The receiver is a delicate Morse instrument of the ink-writing type.

The reader may suggest that there is really no gain in this system, because an operator must punch the paper for the transmitter, and that this operation will take as much time as actual sending. This is true, but the objection overlooks the fact that several operators can be engaged in punching different portions of the "slip." Indeed, the ordinary "automatic" instrument circuit has five operators at each end: two engaged in punching, two engaged in receiving, the fifth engaged in co-ordination of the other four. A batch of six messages is sent one way, then six in the reverse way. The two "punchers" must therefore prepare slip for six messages whilst their previous six are sent and six are received, plus the time required by the controlling clerk to acknowledge receipt or to make small corrections, etc. In this way a far larger number of messages can be transmitted by one line wire. But there are other advantages. In the case of press messages the prepared tape can be used by an operator at London to send to Birmingham, then put successively through other transmitters working to Manchester, Leeds, Glasgow, Dublin, etc.

Printing Instruments.—There are many forms of instruments which print letters in Roman type. The oldest is that of Professor Hughes; that of the Exchange Company of London is used only for sending news to subscribers.

The Hughes' instrument combines both "sender" and receiver in one. It consists of a keyboard like that of a piano, each key marked with a letter. Behind the keyboard is a train of wheels driven by a weight, and

among the wheels is a type wheel, or one on whose rim the letters of the alphabet have been formed, certain stops (full stops, etc.) being included. A paper tape runs under the type wheel.

Among other things moved by the weight is a rotating chariot or carriage, which moves in exact time with the type wheel, so that when a given letter on the type wheel is at the bottom position the chariot is also in a particular part of its rotation. Underneath the rotating chariot wheel a number of pins are arranged circumferentially. Each pin corresponds to a given key. When one of the keys on the keyboard is depressed it raises the pin connected with it so that the pin and chariot come in contact, the circuit is completed, and a current flows to line. As the chariot is moving synchronously with the type wheel, and as the keyboard can be adjusted also to "time" with them, it is clear that the line current will always flow when the type wheel is ready to print the proper letter.

A prime feature of the system is that the instruments at two stations on the line must also move synchronously, ingenious adjustable tension springs being provided to secure it. It follows that the chariot and type wheels are always in exactly corresponding positions, and when the receiving instrument gets the signal its type wheel is just in the right position for the appropriate letter. The current actuates a magnet and causes the paper tape to be raised into contact with the type wheel, and so prints the letter. The paper is also moved forward one space at the same time, so as to be ready for the next letter.

The Exchange Company's Type-printer.— This system is intended chiefly for the delivery of news to many receivers simultaneously. It transmits in one direction only. At some centre, such as the Exchange,

there is a single transmitter, and this sends the appropriate signals to a large number of subscribers. It must therefore use a total current of considerable value, and needs a powerful battery. The appearance of the receiver is familiar to most business people.

The transmitter consists of a rotating barrel *b* (Fig. 123), from which project a great number of pins *p*, only a few of which are shown in the diagram. Each pin corresponds to a particular letter of the alphabet and

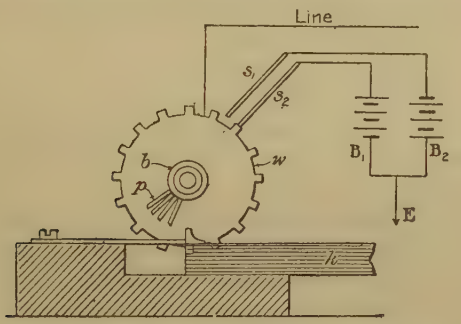


Fig. 123.—Exchange Company's transmitter.

also to a key *k* on the keyboard of the instrument. The barrel *b* is kept rotating continuously along with a contact wheel *w*, whose teeth make contact alternately with two springs s_1 s_2. Two batteries are employed. B_1 has its positive end joined to s_1; B_2 has its negative end joined to s_2. The other ends go to earth E. The wheel *w* is connected to the line wires, and it is clear that, as it rotates and its teeth are touched, alternately by s_1 and s_2, currents will be sent to line which alternate in direction. When s_1 touches *w* a positive current will flow from B_1; when s_2 touches, a negative current will flow from B_2. It is also clear that s_1 and s_2 cannot touch *w* at the same time, and

that the alternating currents they send will flow with great regularity. It must be understood that these currents flow even when no message is being sent. Their purpose is to drive the type wheels of all the receiving instruments and keep them in step with the contact wheel *w*. The regularity of these alternating currents is broken when the operator puts down one of the keys *k*, for each key causes a catch to project and to touch the corresponding pin *p* on the rotating barrel. The effect of this is to stop the barrel and the wheel, and so prolong the duration of the current which may be flowing at that time. We may therefore say that the transmitter provides a constant succession of transient alternating currents, whose regularity is disturbed when a signal is made. We shall now see how this is made to print at the receiving station.

The essential parts of the receiver are shown in Fig. 124. There are three electromagnets, M_1 M_2 M_3, arranged in series, so that the currents from the transmitter pass through all. The action, however, is very different in the three, for the ordinary regular alternating currents produce an effect on the armature of M_2 and M_3, but are too transient to do anything with the armature of M_1. The armature A is strongly magnetised, and moves to and fro between M_2 and M_3 as the alternating currents pass. This to-and-fro motion is reproduced at the upper end of the lever, and its pallets p_1 p_2 drive round the ratchet wheel R and the type wheel T W attached to it. It is clear also that R will move forward regularly at a rate which depends on the alternating currents, and further that the type wheel T W will keep in step with the transmitter wheel *w* (Fig. 123) which sends them.

But while R is moved by each current from *w*, the armature lever L of the magnet M_1 is too massive to

be influenced. As soon, however, as any one of the currents is prolonged by putting down a key of the transmitter the inertia of the long lever is overcome; the armature of the lever L is attracted by M_1 and the other end is made to rise. In doing so it brings a paper tape against the type wheel, so that it receives an imprint of the letter that happens to be at the

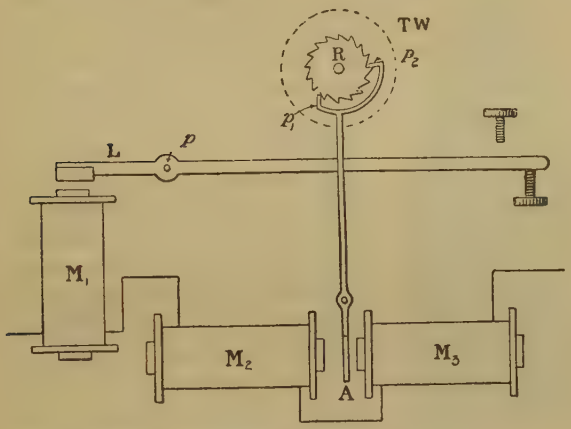


Fig. 124.—Exchange Company's receiver.

bottom at the moment. Now as the wheel T W on the receiver is adjusted to have its letters in positions corresponding to those of the wheel *w* of the transmitter, it follows that the letter printed will be that corresponding to the key pressed down at the other end. Thus let the key corresponding to *k* (Fig. 123) be pressed down. The pin corresponding to it will be arrested by the catch, and at the same moment the receiver type wheel will have K at the bottom position. Just at this moment the current flowing will be continued long enough for M_1 to work its lever and lift the paper

Fig. 125.—The second Atlantic cable, elevation and section.

into contact with the type wheel. Hence the letter K will be printed.

Submarine Telegraphy.—Submarine telegraphy is the same in essentials as ordinary land telegraphy. But the special needs have brought about modifications, some obvious, some quite unnoticed until practical difficulties compelled attention. For example, the question of insulation was altogether revolutionised. The bare conductor supported on porcelain insulators was no longer possible. The air surrounding the ordinary line is an insulator, in fact, a very good one; whereas the water surrounding a submarine conductor is a conductor, and a fairly good one. The first need, therefore, was to cover the conductor by an insulator, the nature of which was at first a matter of anxious investigation. Experience showed that gutta-percha was the best substance to use. It will be interesting to give a general idea of a submarine cable. Fig. 125 is a sketch of a cable laid from the *Great Eastern* steamship in the early days of Atlantic telegraphy. At the centre is a strand of seven copper wires, covered by four layers of gutta-percha, surrounded by tarred hemp, and an outer layer of iron wires covered with hemp.

Earth Currents.—It was soon found that submarine cables were subject to disturbance by earth currents. The operators noticed that they often received signals which had not been caused by the key at the far end, and sometimes these extra signals were superimposed on those coming from the other side. In many cases it became impossible to read; there was an incoherent jumble of marks which could not be interpreted. As a matter of fact, the earth itself was acting as a battery. Differences of electric pressure were being established in some mysterious way: one side of the sea-way was at a higher electric pressure than the other. Hence a current poured into the cable at the earth plate in Newfoundland, say, and passed through it to the earth plate in Ireland, or *vice versa*.

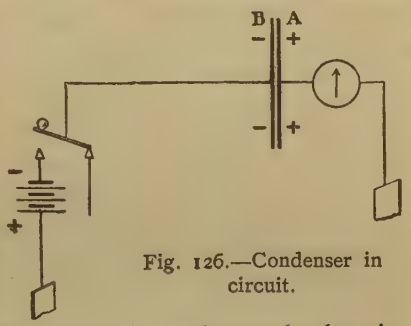


Fig. 126.—Condenser in circuit.

The existence and frequency of these earth currents were a serious hindrance to rapid and continuous working, and therefore had to be overcome if possible. The remedy was found in the use of condensers, by which the continuity of the cable is broken. In Fig. 126 a condenser is introduced into the circuit, and is shown diagrammatically as two straight metallic sheets A and B (seen edgeways) separated by an insulating space.* As this device breaks the circuit, steady

* In practice, a condenser is made by arranging sheets of tinfoil alternately with mica or paraffined paper. The odd numbers of the tinfoil sheets are united to form one large plate; the even numbers form a second. In this way large sheets are packed in small space.

continued currents become impossible, but a sudden rush of electrons is not at all hindered. To get a glimpse of the action involved, let it be remembered that an insulator will allow a slight movement of the electrons it contains. Consider, then, the condenser in Fig. 126; if the negative end (−) of the battery be joined to one plate the electrons in the air (or paraffined paper) are thrust forward towards to the other and give a kind of impulse to it and the cable beyond. This electric impulse is carried along to the other end, and is sufficient to operate the very sensitive receiving instruments now employed.

Retardation of Signals in a Cable.—It was predicted by Faraday that the signals through a long cable would suffer retardation, and experience shows this to be the case. The Atlantic cable, which runs from Valentia, off the coast of Kerry, to America, is 2,350 nautical miles in length, and a signal takes a quarter of a second for transmission. In the Pacific cable (7,847 nautical miles long, in four sections) a signal requires two-thirds of a second (including time spent on a relay). Such times as these are longer than electrical signals take over aerial lines. But they were much longer in the early days, for several inventions make the times shorter than they were. One of these is a more sensitive receiver, which will respond to the first faint arrival of the signal; another is a special way of sending the signals. In early days the retardation was so great that it threatened the commercial success of the cables. For the retardation reduced the number of signals that could be sent per minute, and therefore diminished the revenue which the cable could earn.

The reason for the retardation lies in the form of the cable. Its conductor is separated from the outside

conducting water by a fairly thin insulator. The conductors, moreover, have a very large surface because of their length. Hence a cable acts as a condenser, and when one end of it is joined to a battery the first part of the current does not travel forward, but is spent in *charging* the surface of the copper. Here it remains till other portions of the current have passed towards the other end; it is released when the battery is reversed or when both ends are put to earth. It is almost as if the cable had to be filled before electricity could reach the other end.

Telephony.—The transmission of sounds is an easy matter, and was contrived by Wheatstone long ago. By means of a wooden rod he conveyed the sounds of a musical instrument from one room to another. In other ways the direct transmission of sound by machanical vibration is also well known. The common "speaking tube" consists of a simple tube with a mouthpiece. When spoken into, the aerial vibrations set up by the voice agitate the air at the beginning of the tube and are propagated as aerial waves to its distant end. The efficiency of the tube in carrying the sound to considerable distances depends simply on the fact that its walls prevent the vibrations *from spreading in all directions*. It is this spreading which leads to attenuation when we speak in the ordinary way. If it were not for spreading, an ordinary voice would be heard over an immense distance.

The modern telephone is, however, dependent on a different principle. It starts with acoustic vibrations, as all methods must do which are to transmit the voice. But it immediately transforms the energy of these into a magnetic vibration and then into an electric vibration. Having obtained the energy in this third form, it conveys it along the line to the distant end,

and there transforms back again from the electric to the magnetic and from the magnetic to the mechanical, thus reproducing the sounds which started the series of operations. Reading this, one would imagine that very complicated sets of apparatus would be requisite, but this is quite a mistake. In the early days the apparatus was strikingly simple, and it has become more complex only because of the enormous public demand and the consequent need for securing each subscriber against disturbance or failure, notwithstanding that he is to have power to call for connection with hundreds or thousands of others.

The Human Voice.—The voice is produced when the breath is expelled through the larynx in such a way as to set the vocal cords in vibration. Their oscillatory movement is communicated to the breath and, when this passes the lips, the vibration energy is spent in agitating the whole of the surrounding air.

Consider what this air vibration means. Each particle receives an impulse urging it forwards. It therefore acts on its neighbours, giving to them the energy which was imparted to it, and, having done that, it falls back to its former place. It does not at once rest there, however. It swings beyond, and comes to a standstill only after some surging to and fro. In the case of an ordinary voice the vocal cords vibrate several hundred times in a second, and each particle of air will be agitated and vibrate at this rate. Any substance on which the vibrating air impinges will be also agitated at the same rate. It will feel the higher pressure as the air particles are thrust against it, and also the lower pressure as the same particles surge backwards. The to-and-fro movement of the air particles will therefore be felt as increase and diminution of pressure, and if the substance is a thin, flexible

body it will be bent by these varying pressures, first in one way, then in the other. A thin diaphragm of wood or metal will be bent in ways suggested by Fig. 127. The diaphragm at rest is shown in edge view by the two parallel lines. When agitated it moves from its zero position (the continuous lines in Fig. 127*a*) to one of the dotted positions, and then rebounds into the other. How quickly it will pass from one position to the other depends on the rate of vibration in the sound. A man's voice, having a lower rate, may cause the diaphragm to vibrate 250 times per second; a woman's may set up 600 vibrations per second.

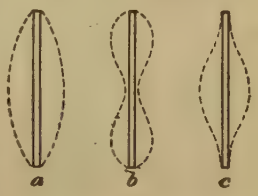


Fig. 127. — Theoretical vibrations of a telephone diaphragm.

This difference in numbers is of course easy to understand. It corresponds to what is called a difference in pitch. An unscientific reader will find it more difficult to see the meaning of sounds which differ in quality. Take, for example, a sweet voice and a squeaky voice. What are the differences between them? This question requires a longer answer than can be given here, but we can *suggest* a part of the answer by showing that the vibration of the diaphragm of Fig. 127 can be varied in form. In *b* and *c* the dotted lines are quite different from each other and from *a*. They are grossly exaggerated in degree, but will suffice to give the reader some idea of the fact that while the vibration number or pitch may be the same, the *form* of the vibration may be different. Scientific men know that the difference is due to the simultaneous development of notes of different pitch. It is with vibrations of air and of a diaphragm that we

start to study the first transformation effected by the telephone. How do we get from the vibration of a diaphragm to the vibration of a magnet?

Simple Telephone.—Fig. 128 shows a simple telephone circuit, including line, transmitter, and receiver. These last two are alike, which was the case in the original device of Graham Bell. Each instrument has a diaphragm *d*, a magnet M, and a coil of wire *w*. The ends of each coil are connected together. When a sound is made near the mouthpiece the diaphragm is set vibrating, and by its motion it dis-

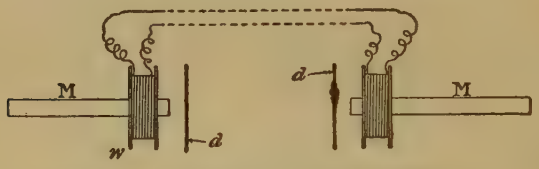


Fig. 128.—Diagram of telephone system.

turbs the "field" of the magnet. Already on page 12 we have shown that iron alters the shape of a magnetic field, and we have now to apply that fact to a telephone. Consider the "field" when the iron diaphragm is in three different positions: first, when it is in the position of rest; secondly, when it is nearest; and, thirdly, when it is farthest away from the magnet. The effect produced on the field by these three positions of the diaphragm is shown in Fig. 129, so far as the lines of the magnetic field are concerned. As the diaphragm comes near, the lines jump into the crowded state seen in *b;* as it recedes the lines jump apart, as shown in *c*. While the plate is vibrating the magnetic field passes from *b* to *c* and back, two or three hundred times a second. Remember, now, that a coil of wire is fixed on the end as at *w* in Fig. 129*a*. It

follows that when the diaphragm approaches, magnetic lines cut the coil one way, and when it recedes magnetic lines cut the coil in a reversed way; or, in other words, when the diaphragm vibrates to and fro the magnetic field will also vibrate to and fro, cutting the coil in a kind of vibratory or alternating way. Now, we have seen that when magnetic lines cut through a conductor, the action produces a separation of the electrons in the conductor and gives rise to a current. Consequently, the vibrating magnetic field will give an alternating or vibrating current of electrons in the coil and also in any circuit of which the coil forms a part.

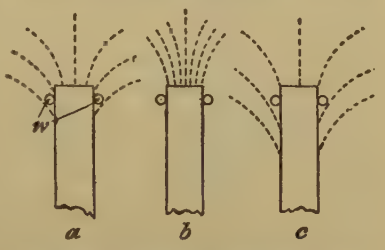


Fig. 129.—Variable magnetic field produced by vibrating diaphragm.

Thus, after three transformations, the vibrations of the air have become vibrations of electrons in the circuit. The actions at the receiving end are just the converse of these. We start with the alternating current which arrives from the transmitter. As it flows one way it strengthens the field of the magnet, as it flows in the reverse direction it weakens the field. This is the first transformation. As the field weakens and strengthens it will attract the diaphragm with varying force, setting the iron into vibration at just the same rate. This is the second transformation, and it soon produces the third, for the vibrating diaphragm sets the air in similar motion, and we thus get disturbance in the air like that which started the long cycle of changes. If the reader has followed the foregoing

explanations he will be able to realise that when he speaks into a telephone his voice exists successively in the form of a vibration in (1) the air, (2) the telephone diaphragm, (3) the magnetic field, (4) the electrons of the circuit.

The explanations given do not cover all the facts, nor do even the most technical theories go quite far enough to make them all clear; but, substantially, the statements may be relied on. The two telephones as devised by Graham Bell were very ingenious and very original devices for transmitting speech by electrical agency. Their faults were not noticed at first, nor did they begin to appear serious till it was desired to telephone over long distances. It was then discovered that the sounds reproduced were very feeble. The extra length of wire introduced extra resistance, and, as Ohm's law (page 70) would lead us to expect, the currents were too weak to produce audible sounds. This was remedied by a device known as an induction coil, by which the method was considerably altered.

A Telephone Induction Coil.— This consists of three parts: (1) a straight iron core, built up of soft iron wires; (2) a primary coil, consisting of a small number of turns of insulated wire; (3) a secondary coil, wound over the primary. The secondary coil is wound with thinner wire and has many more turns. Fig. 130 gives a general idea. The primary coil *p* (Fig. 130*a*) is shown in thicker outline and is connected to a battery B, through an adjustable resistance R. The coils *s* of the secondary are not connected in any electrical way with the primary, yet, by means of the magnetic field produced by one, electrical changes are set up in the other.

Let us suppose a current flows from the battery B

(Fig. 130*a*) through the primary coil. A magnetic field is produced, and will remain as long as the current flows. Suppose now that the resistance R is suddenly changed by moving the contact. If R be increased the current through *p* will increase, if R be diminished the current will fall. Now, each change in the current

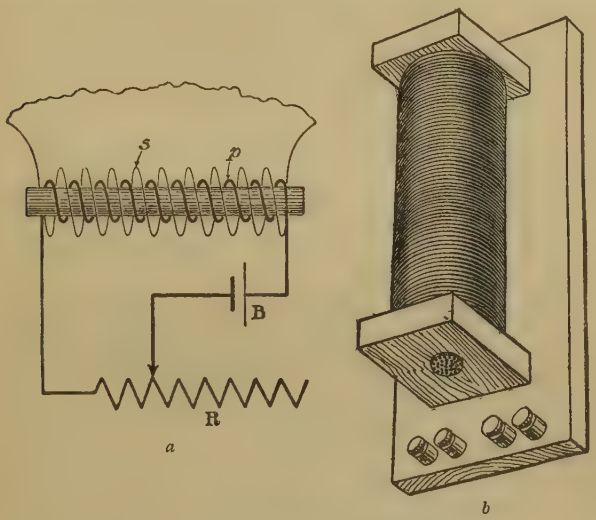


Fig. 130.—Induction coil diagram.

produces a corresponding change in the magnetic field. A stronger current gives a greater flux of lines, a weaker current means a smaller number of lines. These changes in the number of lines act on the electrons in the wire of the secondary coil. An increase of the lines means that the extra ones push out from the core and cut through the secondary, a fall in the lines means that some move back into the core and seem to vanish, so that they cut the secondary coil

in a reverse way. Fig. 130*b* shows the general appearance of the coil.

A little consideration will show, therefore, that changes in the primary current must produce electric pressures in the secondary. If the secondary coil has a large number of turns the electric pressures produced in it are high, because the voltage of one is added to that of the others. Omitting the intervening steps, we may say that changes in the resistance R give rise to electric pressures and currents in the secondary, and that the pressure may be high if the changes in R are rapid enough. When R fluctuates we shall get a fluctuating or alternating voltage in the secondary coil.

Fig. 131.—Microphone without carbon.

We shall now explain how the vibrations of a sound are used to produce a varying resistance and, therefore, a varying current. The many pieces of apparatus used for this purpose all depend on the peculiarity of a loose contact between conductors, but more especially between pieces of carbon. If the contact is very light the resistance is great; under high pressure the contact resistance becomes so small that it is negligible; with intermediate pressures the resistance has an intermediate value. Consider Fig. 131. A battery is joined to a telephone through two loose contacts made by one iron nail bridging two others which lie side by side. Through this circuit the battery sends a current, generally a small one, because the loose contacts offer an appreciable resistance. If, now, anyone speaks to the three nails—that is, to the loose contacts—the varying pressures produced result in varying resist-

ances and, therefore, in varying currents. The telephone is at once able to reproduce the sounds, even though it be situated at some distance. For long distances the loose contact must be improved and an induction coil introduced, as in Fig. 132. At each station there is a battery B_1 B_2, a loose contact or microphone M_1 M_2, a telephone receiver R_1 R_2; also keys K_1 K_2 in the microphone circuits, these being necessary to prevent the battery from running down. The microphone circuit need not be complete except when

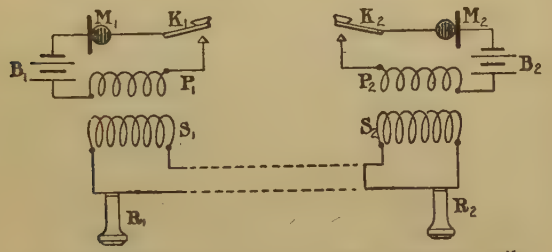


Fig. 132.—Telephone system with induction coils.

communication is proceeding. The receivers R_1 R_2 are exactly like those already described; P_1 P_2 and S_1 S_2 are the primary and secondary coils, shown apart for clearness.

The speaker, say at station 1, puts on his key K_1 and speaks to the microphone. This causes a fluctuating resistance in the battery circuit and sets up a fluctuating voltage in the secondary coil and line. This voltage is high enough to give an audible effect at the other end, even when the second station is a long way off. It must be observed that the current does not give rise to the reverse transformations here that were found in Bell's magnet telephone. It passes from the line, through the secondary coil, to R_2, without affecting the

primary. In the receiver R_2 it produces just the same actions as those described in the case of the simpler instrument.

Microphones.—A microphone does for sound what a microscope does for sight. It magnifies feeble sounds and makes some audible which were quite unknown before. Professor Hughes, who was the first to work systematically at the subject, was able to demonstrate the sound made by a common house-fly as it walked about inside an ordinary match-box. He did this by placing the match-box on the top of a loose contact like that of the three nails in Fig. 131.

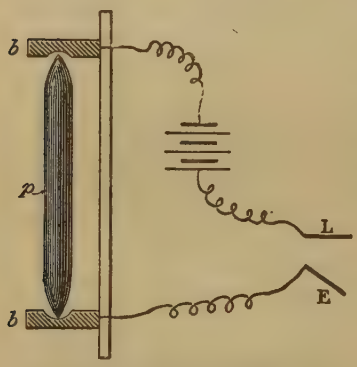


Fig. 133.—Simple carbon microphone.

A better form is shown in Fig. 133. It consists of a carbon pencil *p* standing loosely in little cups formed in carbon blocks *b b*. Of these, one is attached to a battery, the other is connected, say, to earth E, and the second terminal of the battery goes to line L. Under varying pressure these loose carbon contacts give very excellent results, and the microphones now used in all telephone transmitters are developments of the form shown in Fig. 133.

Fig. 134 shows the Gower-Bell microphone long used in the Post Office transmitter, and Fig. 135 is a section of the form now used. This last is a modification of the Hunning's microphone, which consists of a carbon plate as one terminal, an iron diaphragm as

the other, and a quantity of carbon granules nearly filling the space between them. When spoken to, the diaphragm pressed more or less on the granules and varied their resistances. Although a very good microphone, the Hunning's had the fault of allowing the granules to become packed, so that after a while they were not so responsive to varying pressure. This fault led to the modification now used, known as the

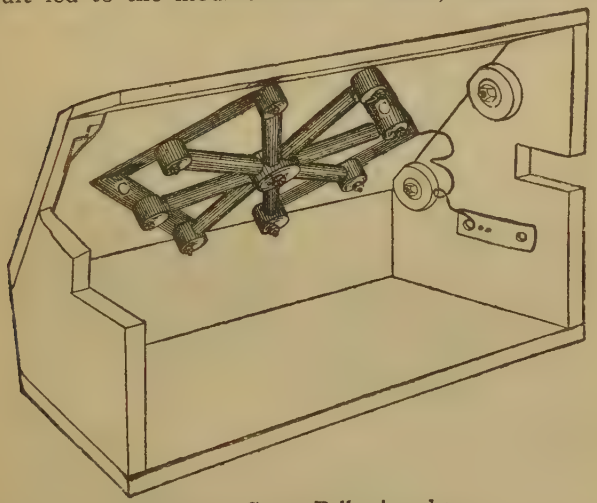


Fig. 134.—Gower-Bell microphone.

Hunning's cone or Deckert transmitter. The chief difference is shown in Fig. 135*a*, where the carbon plate C is seen to have one of its faces in the form of a series of pyramids. This results in the space between it and the diaphragm D being cut up into a number of small cells, each containing its share of the carbon granules. This division prevents packing. A further improvement consists in cutting some of the central pyramids short and fastening tufts of silk on them (Fig. 135*b*);

these act as dampers, preventing the diaphragm being disturbed by sudden jerks, but permitting continuous vibrations.

We have now explained the method by which a telephonic message is transmitted, so far as the instruments are concerned. The method of connecting is, of course, more or less difficult and somewhat beyond

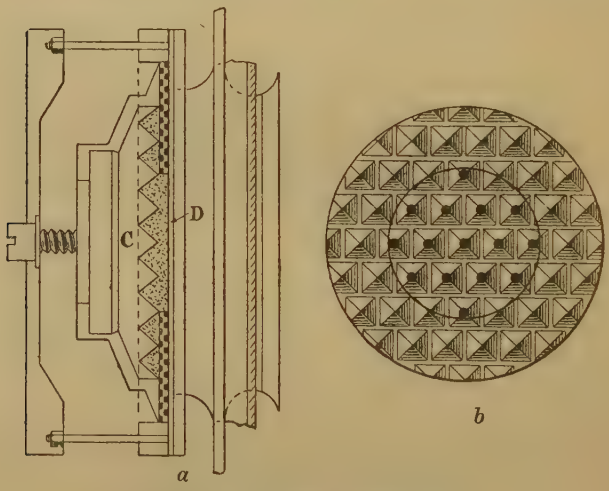


Fig. 135.—Deckert transmitter.

the scope of this volume. A brief notice of these matters must suffice.

We shall explain briefly: (1) the method by which attention is obtained; (2) one method of arranging connections so that the change from "calling" to "speaking" is made with sufficient readiness.

1. Method of making calls. This has been generally done by a small hand dynamo, called a "magneto," because its magnetic field is due to permanent steel

magnets. When the "call" handle is rotated a series of rapidly alternating currents are generated and move the armature of a polarised relay P R at the other end. This bell is a special one, having a polarised armature after the general fashion of that in the polarised relay (Fig. 122).

2. One arrangement of connections is shown in Fig. 136. The telephone receiver R is usually hanging

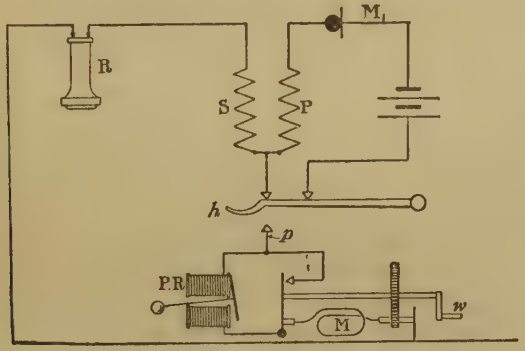


Fig. 136.—Telephone connections.

on the hook *h* and pulling it down into contact with the lower point *p*. As the diagram stands the telephone has been removed and the connections are right for speaking. The hook *h* completes the circuit of the battery and primary coil P. Words are spoken to the microphone M, and its fluctuating resistance under the sound waves causes a vibratory current in the primary coil P. This sets up a corresponding vibratory current in S. The secondary current goes to line, and is reproduced in the distant telephone as speech.

When the telephone receiver is hung on the hook the latter puts the magneto M_1 to line.

CHAPTER X

WIRELESS TELEGRAPHY

This part of our subject has attracted the attention of the general public in an extraordinary degree. To them it seems astounding that a signal made by an apparatus, say in England or the United States, can be detected 1,000 or 2,000 miles away without a wire or other conductor to convey an impulse from one station to the other. To the public the mystery lies in the absence of the wire. People have grown accustomed to telegraphy by wire, and this generation does not know that its predecessor was at first equally astonished at the idea of telegraphy by any electrical device.

A little consideration will show that the astonishment and sense of mystery arise out of a neglect of the universal and omnipresent ether. When an electric signal is made anywhere it starts a disturbance in the ether (*see* page 25), and any such disturbance is propagated by the ether in all directions and to all distances. The invention of wireless telegraphy waited for a method of detecting these disturbances of the ether. One of the greatest of modern scientific men, Professor Clerk Maxwell, had described the conditions under which disturbances took place, and had wrestled in vain with the problem of finding a detector. The discovery came from a young German physicist, named Hertz, and when it came it was found to be very simple. It soon afforded proof of the truth of Clerk Maxwell's predictions, and speedily developed into the practical forms

of wireless telegraphy. Before we pass to these let it be noted that the name "wireless" is a poor and misleading name. It simply excludes the idea of a conductor and leaves us without help as to the means. From what has been already said, it is easy to see that the correct name is "Etheric telegraphy," for the

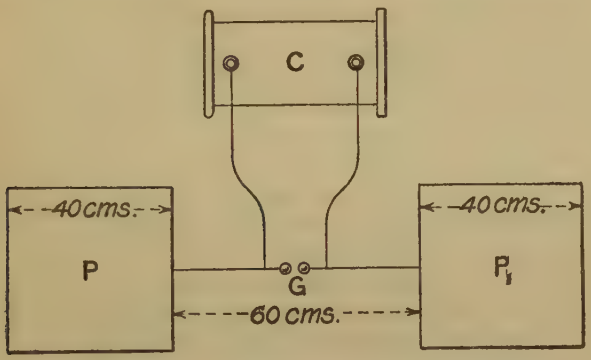


Fig. 137.—Hertz transmitter for wireless telegraphy.

ether is the medium by which the action is transmitted from place to place. In this view, wireless telegraphy merely means telegraphy without wires, and may mean signalling by semaphore, or by flag, or by the sun's rays. But if wireless telegraphy means that we are using electrical actions and yet dispensing with conducting wires for propagation to the distant stations, it is only an indirect way of saying that we rely on the ether, and that the system is "etheric."

Transmitter and Receiver.— We shall first describe the simple transmitter and receiver by which Hertz laid the foundations of etheric telegraphy. As seen in Fig. 137, the transmitter or radiator consists

of two metallic sheets P and P_1, each about 16 inches square. Attached to each sheet is a stout wire ending in a well-polished metallic ball. Between the balls is a short air gap about half an inch wide. The wires are joined to the terminals of an induction coil C, as shown in the figure. The coil will be described in a later section.

The method of using this simple apparatus as a transmitter is as follows. The plates P and P_1 are oppositely electrified by the coil, and the electrical charges are increased till the pressure becomes too great for the air gap to bear. When this happens a spark jumps across the gap G. In the act of sparking the sheets are discharged; the positive and negative electrons neutralise each other, and the plates are ready for another charging.

Let us now see how this charging and discharging affect the ether so as to produce a series of waves in it. Notice, to begin with, that "charging" involves something more than merely giving a positive charge to P and a negative charge to P_1. As explained on page 13, the charges involve an electric "field" in the space between them; that is to say, the charges produce *a state of strain in the ether* (*see* page 13 and Fig. 15). When the spark occurs the charges flow together and the electric "field" disappears, shrinking into the conductors as the charges come together. As this electric field disappears a magnetic field springs into existence and spreads outwards, this being due to the *current* formed by the flow of the charges. We can represent these states of the ether by line diagrams like those of Fig. 138*a* and 138*b*.

Stage I.—In the first the plates P_1 and P_2 are seen edgeways and are shown by thick lines. The electric field in the ether is represented by dotted lines, each

line stretching from a portion of the positive charge on P_1 to a similar portion of the negative charge on P_2. The field thus indicated stretches over a fair distance, but rapidly falls off in intensity, and could not possibly be detected at a distance of 25 feet. The field extends all round the radiator: in the figure it is shown only on one side.

Stage II.—Now let the discharge commence. The

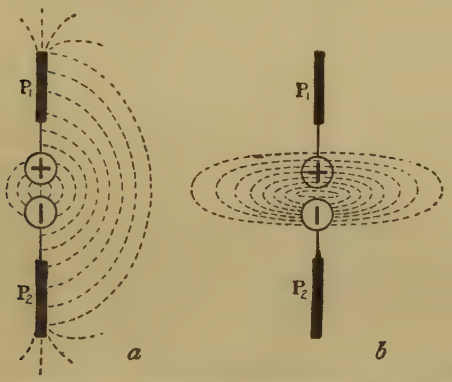


Fig. 138.—Electric and magnetic fields set up round transmitter.

positive charge travels downwards, carrying the ends of the flux with it; the negative charge travels upwards, carrying the other ends of the flux with it. Consequently this means that the charges come together, and further that the field is concentrated and practically vanishes from the surrounding space. It falls back on the conductors whence it sprang and the stress in the ether vanishes.

This movement of the charges is really a current or flow of electrons, and we know that such a flow is accompanied by a magnetic field. This may be

suggested by the dotted lines of Fig. 138*b*. The magnetic flux thus depicted spreads out as the electric flow increases and falls back again on the conductors as the flow ceases. But we must not suppose that the discharge is completed by a mere flow of + and − charges. If that were so the two effects on the ether would be a stress due to the electric field followed by an eddy due to the magnetic field. But there are other stages in the discharge which must now be mentioned.

Reversal on Discharge.—When charged bodies, like the plates in Fig. 138, are discharged, the action is very rarely ended by a simple flow of the electrons one way or the other. In the act of moving they acquire a momentum which carries them beyond the mark, with the result that the plates get charged in senses contrary to their initial state: P_1 becomes negative, P_2 positive, and of course an electric field is established once more. This second field, however, although otherwise like the first one, is reversed in direction. The formation of this field may be called the third stage in the discharge.

The reversed charges now start a second discharge and give rise to a magnetic field, also of reversed direction, because the electrons are now flowing in a contrary direction. This may be called the fourth stage. In this discharge the electrons again overshoot the mark, and the plates become charged in the original sense.

The further effects can now be imagined by the reader. The plates are not discharged by a straightforward and simple flow but by a series of electric *oscillations;* each plate is alternately positive and negative, the flow is alternately up and down (Fig. 138). Similarly there is first an electric field, then

a magnetic field, then a reversed field of each kind, one field alternating with the other, each spreading out into space in a way which cannot here be specified. The foregoing explanation is sufficient to show that when the plates P_1 and P_2 in Fig. 138 are charged and discharged a whole train of electric and magnetic waves is sent out into space. Strictly speaking, the waves are not simply electric *and* magnetic, but a disturbance of the ether which embodies both.

So far we have dealt with the transmitter. It may be helpful to point out that there are many mechanical analogies to the way in which the charged bodies get discharged by oscillation into opposite states. When the transmitter is charged it distorts the ether, after the style in which a spring may be distorted by compression, or extension, or bending. When such a spring is released it rushes towards its undistorted condition, but acquires such impetus that it is carried into an opposite distortion. If it were compressed at first, it now becomes extended, and so on. It comes to rest after a series of oscillatory movements.

The same is true of a pendulum which is disturbed from a position of equilibrium. It is also true of compressed air. If a bottle containing compressed air be liberated by opening a tap the excess air flows out, but the movement is oscillatory. The first rush carries out more than the excess, and for an instant there is a partial vacuum, followed by a flow into the bottle, and so on. In these cases (spring and compressed air) a series of waves is set up in the spring or the air, just as a Hertz electric oscillator sets up a series of waves in the ether.

Before leaving the transmitting part of the apparatus it will be well to describe the type of induction coil used for these experiments, especially as it has

served for all the earlier work on public etheric telegraphy.

Induction Coil.—There are five parts of the induction coil which may be said to be adequate for the purpose of etheric telegraphy. These are: (*a*) the iron core, (*b*) the primary coil, (*c*) the secondary coil, (*d*) the make-and-break, (*e*) the condenser. These will be described in order. A general view appears in Fig. 19 (page 20) and a diagram in Fig. 139.

(*a*) The iron core is made of iron wires collected into a bundle so as to make a cylinder. The length and thickness vary; for a core 12 inches long the diameter is nearly 1 inch. The wires are tightly bound together so as to be as compact and firm as possible. It is necessary that they should not be in easy conducting contact, but a slight film of oxidation or dirt suffices to insulate them. The thinnest film of varnish is ample.

The object of the core is to make it easy to get a large flux of magnetic lines when a current passes through the primary coil. The iron wire ought therefore to be chosen for its good magnetic qualities. It ought to be readily magnetisable to a high degree of intensity, and it ought to be equally ready to part with its magnetised condition.

The core is insulated thoroughly, lest sparks pass to it from either the primary or secondary coil.

(*b*) The primary coil consists of 200 or 300 turns of thick wire enclosing nearly the whole length of the iron core. It is generally in two layers, and is connected to the battery through an automatic make-and-break, as shown in Fig. 139.

(*c*) The secondary coil consists of many thousands of turns of thin, silk-covered wire, wound outside the primary and having a specially good insulator between them.

(*d*) The make-and-break consists of a flexible flat brass spring *s*, carrying an iron block *i* at its upper end. Its other face also carries a short platinum rod *p*. This platinum rod touches a similar one forming the end of a contact screw *c.s.*, working in the stout brass support *b*. The degree of pressure between the two platinum rods can be adjusted by this screw.

(*e*) The condenser consists of sheets of tinfoil interleaved with paraffin paper, and has been already described and explained (*see* footnote on page 209).

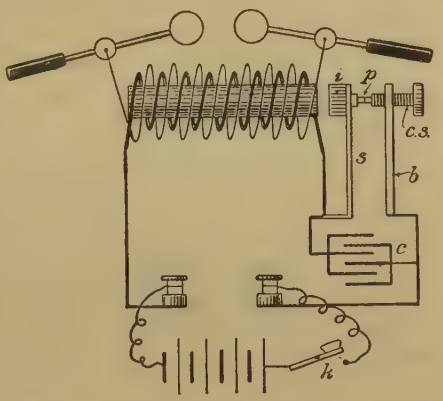


Fig. 139.—Diagram of the induction coil.

In the section on telephones we have explained the action of a simple induction coil, consisting of core, primary and secondary. A current flowing through the primary magnetises the core and creates a magnetic field. This cuts through the convolutions of the secondary coil and sets up a high electric pressure. In the simple telephone coil the effects were produced by mere variations in the strength of the primary current. In the coil we are now describing the intention is to augment as much as possible the effect produced by *suddenly stopping* the primary current and to neglect all other actions. This is the object of the make-and-break and the condenser *c*.

Let us consider the actions that follow when the switch *k* is closed. The primary current begins to flow and increases in strength, magnetising the iron core to higher degrees of intensity as it does so. A magnetic flux is gradually developing and passing out through the secondary coil, producing a pressure of high value. Notice that this primary current flows from the contact screw *c.s.* through the contact points of the platinum rods in the make-and-break.

At a certain moment the iron core is so strongly magnetised that it drags the iron block *i* and its brass spring violently towards itself, and so moves one contact away from its fellow; in other words, *the magnetic attraction breaks the primary circuit.* This leads to a very rapid collapse in the magnetic field, and as the magnetic lines fall back on the core the whole of them cut through the secondary at an enormous rate, producing a very high voltage indeed.

But, high though this pressure is, it is greatly increased by the use of a condenser. When the primary circuit is opened the primary current does not stop at once. It has a kind of momentum which carries it forward across the gap formed at the points *p* (Fig. 139), and appears there as a spark. The desirable thing is that the current should cease instantaneously as the contacts part company; the spark means that it is continuing, of course declining in strength as it does so. One consequence is that the magnetic field does not fall to zero as quickly as it might. Now the condenser absorbs the momentum of the current and practically prevents the spark. As the gap forms the current finds a way into the condenser, charging it up to a very high value. The primary current stops with remarkable suddenness, and the voltage in the secondary is increased in an astonish-

ing degree, sometimes in the proportion of 8 to 1. A coil like that now described can easily produce a pressure of 100,000 volts.

Referring back for a moment to the Hertz radiator in Fig. 137 (page 225), we see now that the plates are charged to an enormous potential before the spark takes place, that an intense electric field will be set up in the surrounding space, and that as the spark jumps across the gap a violent electric and magnetic wave will begin to be propagated through the surrounding ether. This occurs every time the spark takes place—that is to say, a train of waves follows every spark. There may be fifty or a hundred electric oscillations following every spark, but they are so rapid that the whole number is over in a very small fraction of a second.

The Receiver.—Let us suppose that a Hertz transmitter is sending out its electromagnetic waves; we have to see how they can be detected. At very small distances the electric and magnetic effects are easily found separately, but they are not due to the system of waves, but to the initial states. The difficulty comes when one receiver is some distance off, so that even electric and magnetic actions which are strong at the transmitter itself cannot be detected. How are we to find the waves when attenuated by travelling over great distances? The answer to this question was found when Hertz used a simple circle of wire (shown in Fig. 140) having a gap *g* in it. The electromagnetic waves fell on this, and culminated in producing a minute spark between the two balls at *g*. It was found that the circle must have a given diameter or the spark would not be seen.

The reason for this is very interesting. It depends on the principle known as resonance, or sympathetic vibration, on which a few words must be written.

Let two pendulums be suspended from a common support, and let one of them be put into vibration. After a little while the second pendulum will begin to vibrate, *provided that its time of vibration coincides with that of the first one.* If the vibration time is identical the first swing of pendulum A will give a minute impulse to B. Just as B is recovering from the

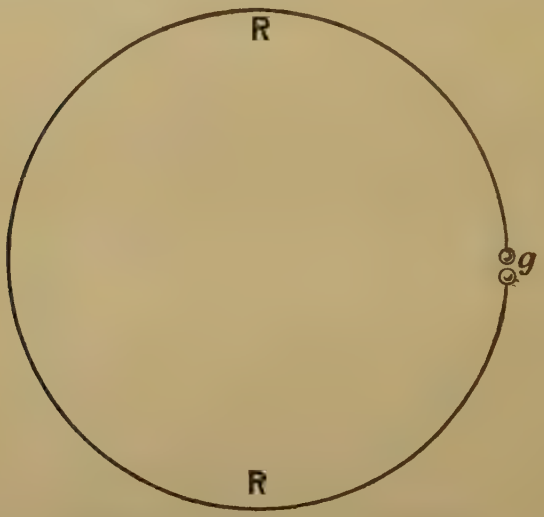


Fig 140.—Hertz receiver for electric waves.

effect of this and, therefore, is moving back it receives a second impulse, reversed in direction, and the effect is added to that of the first. This timing of the impulses goes on with each move of A until, by the *accumulation* of small effects, B is made to vibrate over quite a large distance.

Again, a tuning-fork is make to vibrate and then held against the case of a piano. One of the strings begins to vibrate and emit a note, this string being the

one which has the same time and frequency of vibration as the tuning-fork.

Hertz's Receiver and Resonance.—The reason why Hertz's receiver must be a certain size is now clear. An electric wave requires some time to go round any conductor, and this time depends on the size of the conductor. If the electromagnetic waves from a transmitter are to produce a spark at the gap in a receiver it must be by the accumulation of the small impulse of one wave being added to that of the other waves which precede and follow. This can only be done when the electric movements produced in the receiver are able to surge to and fro in the time that elapses between one wave and the next. When that is the case the impulses accumulate, and finally gather such strength that the spark is made. This may be put in another way. The first impulse disturbs the electrons in the circle of wire and makes one ball positive and the other negative. Just when this impulse is dying away and the electrons are returning, the second and reversed impulse arrives, also urging the electrons back. The second ball is now made positive, the first one negative, and the intensity is greater because of the addition of the impulses. The electrons again begin to return, and as they do so receive the third impulse, acting in such a way as to hasten the motion they have themselves begun.

To get a good detector the circle should have such a size that an electric wave can pass to and fro in the same time as that taken in the transmitter. The receiver and the transmitter must, in fact, be sympathetic—that is, they must have the same natural time of electric vibration.

Properties of Electromagnetic Waves.—Having devised a transmitter or radiator of waves, and having

also obtained a sympathetic receiver, Hertz found that he could study the properties of these electromagnetic disturbances.

Transmission and Reflection.—Waves were propagated in all directions from the transmitter as a centre. They passed not only through air, but also through all non-conductors. They could not pass through conductors, but were reflected from their surfaces just in the same way as light is reflected from a mirror.

Hence, Hertz could send signals through stone walls. These and other substances were *transparent* to the waves, just as red glass is transparent to red light. On the other hand, Hertz made excellent mirrors out of sheets of zinc or copper, and could reflect the waves in any direction he wished, although the reflected waves were quite invisible.

Refraction.—The waves could also be bent and brought to a focus by lenses in the same way as light. In the case of electromagnetic waves, the lenses might be made of glass, or sulphur, or stone, or pitch, or any other non-conductor. The net result of all this is that the electromagnetic waves are a species of light, and further experiment proves that the only difference is a difference of frequency in the vibration.

Etheric Telegraphy by Hertz's Apparatus.—Hertz made experiments to see at what distance he could detect the waves emitted by his radiator. At first he worked in a large room. Afterwards he took his receiver into another room and detected the waves, although they had passed through the intervening walls. He then passed out into the grounds of the college in Karlsruhe, in which the experiments were made, and succeeded in detecting the waves at distances which then seemed to be very great. It was possible, therefore, to signal by electromagnetic waves,

but no sustained effort was made to develop the subject in that direction.

Other workers in the same direction were Sir Oliver Lodge (who started an independent course of investigation on lightning and arrived at nearly the same results as Hertz), Fitzgerald, Trouton, Righi, etc., but into their work we need not enter.

The Coherer.—Though there were many improvements in the form of the transmitter and receiver as made by Hertz, the early ones were not of real importance for telegraphic purposes. The first great advance

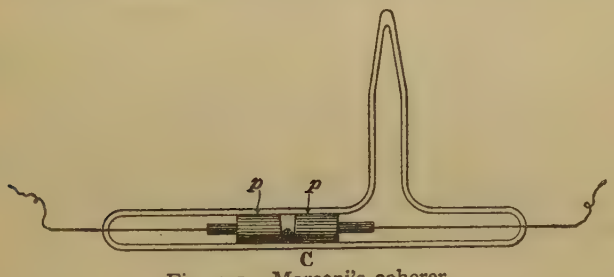


Fig. 141.—Marconi's coherer.

came in 1891, when Professor Branly of Paris discovered what is now known as a *coherer*. This is a device of startling simplicity, and yet one that acts as a relay by which the feeble radiation from a distant transmitter can be reinforced by local sources of power. Fig. 141 shows a coherer c consisting of a glass tube in which are two conducting plugs *p p*, having between them a number of metallic filings. The filings are slightly compressed between them, and it would appear that, as plugs and filings are conductors, a current ought to flow when the wires are joined to a battery. Experiment shows, however, that, to all intent and purpose, electricity does not flow. The many contacts

of filing with filing introduce a barrier, and the coherer practically acts as a non-conductor. But, if the faintest electric wave falls on the tube, the conducting difficulty is removed and the battery is able to send a current through the filings. Branly's discovery therefore comes to this : that a loose assemblage of conductors may act as an unstable body which is transformed from a very poor into a very good conductor as soon as an electric wave falls on it. It was at once obvious that this coherer would increase the utility of Hertz's apparatus, because it could act as a relay and make a local circuit.

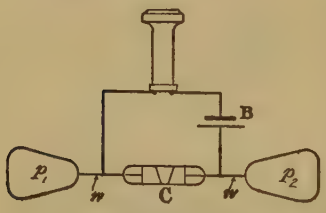


Fig. 142.—Receiving apparatus with coherer.

In Fig. 142 a coherer C is joined to two plates p_1 p_2. A battery B and a telephone are also joined across the coherer at w w. When the electric waves strike p_1 p_2 and w w they make C conduct, and B sends a current through the telephone and gives the signal. To give the receiving wires a greater chance of catching the waves and of absorbing the energy from them, the wires w w are extended by metallic plates fixed on their ends.

A coherer presents one disadvantage. When once the filings conduct they continue to do so until shaken free again. Hence a second signal is not helped by the coherer, for it is continuing to make a signal from the effects of the first. This difficulty is overcome automatically by means of an anti-coherer very much like an electric bell with its clapper. When the coherer first acts and allows the local battery to work the Morse instrument, a clapper is made to strike the coherer and shake the filings into a non-

conducting state again. They are then ready for the next signal.

Many other forms of coherer have been devised.

It is now known that Professor Hughes invented and used a metallic coherer in 1878, and it is also believed

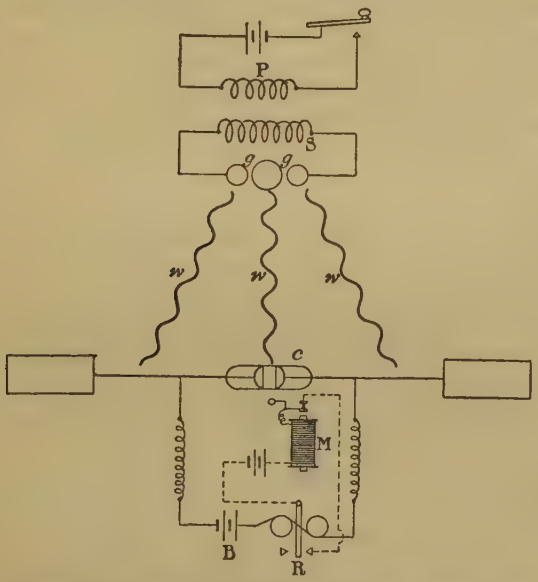


Fig. 143.—General view of receiver and transmitter.

that he had detected electric waves produced by a spark. Unfortunately he did not prosecute the matter further, having been overruled by the opinion of Professor Stokes, who thought the effects produced were due to an ordinary magnetic field arising from the sudden current rather than from a true wave.

General View.—Fig. 143 gives a general view of transmitter and receiver. At the top we have the

battery and key working P and S, the primary and secondary of the induction coil, and producing sparks at the spark gaps *g g*. From these there spread out the electromagnetic waves *w*, which finally strike the receiving wings and surge through the coherer C. Making this into a conductor, they enable the battery B (at the bottom) to send a current through the relay R, and so make contact in the final circuit shown dotted. The current in this works the magnet M, brings down its armature, making a signal, and at the same time striking the coherer with its other end and bringing it back to its non-conducting state ready for the next signal.

The Work of Marconi.—Among those who experimented with the Hertz transmitter and receiver, and who used also the Branly coherer, the most important was Marconi. He soon made great improvements. He improved the coherer, using nickel-silver filings with silver plugs. Fig. 141 (page 237) is after his pattern. It will be observed that the plugs *p p* are bevelled so as to form a wedge-shaped space for the filings, and that these do not fill more than half this space. Marconi's chief improvement, however, was in the transmitter. Hitherto it had consisted of a spark gap and two wings more or less like the plates in Fig. 137 (page 225). The wings had been made of various forms : plates, spheres, triangles, etc. Marconi altered this. One wire from the spark gap was taken to a metal plate laid on the ground; the other side of the spark gap was joined to a metal can or cylinder fixed at the top of a pole. Practically Marconi joined his spark gap to earth on one side and raised the wire from the other side as high as convenient. His receiver consisted of a coherer with one end joined to an earth plate and the other to an elevated conductor.

Fig. 144 is a diagram of Marconi's arrangement in the year 1896. At the transmitting station we have the spark gap S, connected below to an earth plate E and above to a wire upheld by a kite K_1. The spark gap is connected to the secondary terminals of the induction coil I, which is worked by the battery B.

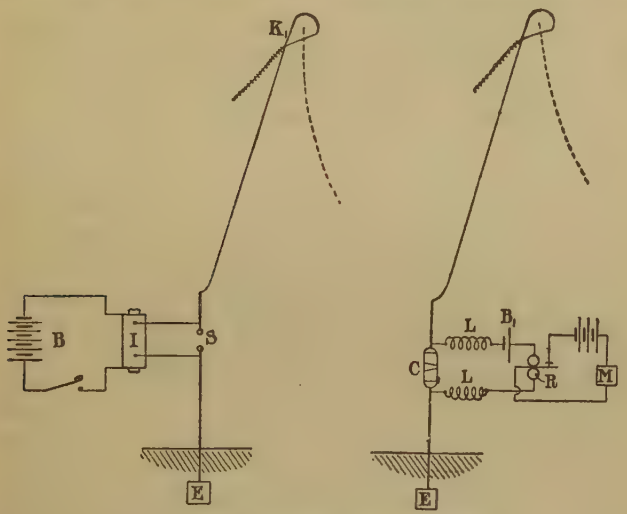


Fig. 144.—Marconi's aerial system.
(*After Fleming.*)

The key enables the operator to charge the system and get a spark whenever he chooses. By keeping it down for a moment only a short spark is produced and a few electromagnetic waves travel outwards. By keeping the key down a longer time a series of rapid, almost continuous, sparks occur and a more prolonged series of waves travels outwards. These correspond to a dot and a dash respectively.

The receiver consists of a coherer C joined to an

earth plate E, and also to an aerial line supported by a kite. When the waves reach the receiving station and fall on the aerial conductor they agitate the filings in the coherer and bring down its resistance. The battery B_1 at once sends a current through the coherer circuit and works the relay R, thus producing a signal on the Morse printer M.

It will be observed that between the battery B_1 and the coherer there are two coils of wire L L. These formed part of Marconi's improvement. Their purpose is to make the coherer act more certainly. Looking at the aerial line, it is evident that when a wave is travelling up and down it has two paths open to it, one through the coherer, the other through the coils to battery B_1 and relay R. If any of the wave goes through this latter path it is useless, for it will not work the relay, and yet it robs the coherer of part of the incident energy. Now coils of wire such as L L in Fig. 144 prevent this splitting up of the electric wave, and compel it to move entirely through the coherer. They do this because of their form. They have what is called a large electric inertia. They do not permit very rapidly changing currents to flow, because of this inertia. Hence the rapidly reversing impulses produced by the waves can get through the coherer easily, but cannot turn aside through the path containing the battery and the relay. Thus the coherer gets the full effect of the wave disturbance, and is all the more likely to become a conductor. Take away these coils and some of the wave would get to earth through the battery circuit without touching the coherer.

It may be helpful to say that Marconi's use of the aerial is to some extent comparable with that of a man who puts his hand to his ear when he wishes to detect feeble sounds. His hand enlarges the space

from which he gathers the sound waves, and in the same way an aerial increases the space from which an electric receiver gathers the electromagnetic waves.

Syntonic Etheric Telegraphy.—There is an obvious objection to etheric telegraphy which cannot apply to that conducted through an ordinary circuit. With an ordinary line the operator knows where his signal will go, and in general he knows that no one else will be able to get it except the man at the station he wishes to work with. But in the case of wireless telegraphy there is no secrecy; the transmitter simply disturbs the ether and the ether *propagates the disturbance in all directions,* just as the air, disturbed by a shout, carries it in all directions. One consequence of this is obvious. A signal intended for a station at P would reach all other stations within the radius of action, and could be read by Q, R, S, T, etc., etc. Now even if we suppose that there was no secrecy about the message, there is still the objection that the signals from various stations might interfere. That is to say, a receiver at P might get a jumble of signals because R, S, and T were all signalling at once, and the signals from one station were running into those from another.

There are two ways of meeting this difficulty. One is by so arranging the apparatus that the waves travel outwards in one direction only, like a beam of light from a searchlight lamp. This prevents stations not on the line of communication from receiving the signals or being disturbed by them. The second method is by synchronising the apparatus at a sending and receiving station so that they will respond to each other, but not to waves of different rapidity or frequency. This is known as "syntonic" telegraphy. Something has

already been said on this point on pages 235, 236. Hertz depended on it to a considerable extent, but after the invention of the coherer less attention was paid to it. When many stations began to send out waves, syntony again began to claim a closer study. A brief explanation will suffice.

Every line, circuit, or apparatus subject to an electric disturbance has its own time of vibration. Suppose a charge given to an aerial by an instantaneous contact with a positively-charged body. This charge finally settles down as a uniform distribution of electricity, but not till it has surged up and down once or twice. In thus surging up and down the charge completes one cycle of its movement in a definite time, depending on the dimensions of the aerial, etc.—strictly speaking, on its electrical capacity and its inductance. Capacity (of a condenser) is explained on page 209. Inductance means the magnetisability of the apparatus, that is, the degree in which magnetic lines are set up by an electric flow. It is much greater for a coil than a straight wire. Now a circuit responds to a train of waves much more easily when they coincide in time with its own natural period. Therefore by arranging to alter either the capacity or the inductance of a circuit it can be "tuned" to a series of disturbances having a given time of vibration. Fig. 145 shows Marconi's syntonic system: s is the spark gap; the induction coil and battery are on the left of it and are omitted from this diagram. The spark balls are connected to a condenser *c* through a coil *p*, and the oscillation time will be governed by the capacity of *c* and the inductance of *p*. The spark sets up oscillations in *p* which are reproduced in *s* and the antenna connected to it, for *p* and *s* practically form a second induction coil. Notice further that the oscillation time

can be still further altered by shifting the contact point on the coil l, for this puts more or less inductance in the antenna's circuit.

We can imagine, then, how easily the waves emerging from the transmitter can be given almost any vibration time.

Turning to the receiver, we see a corresponding set

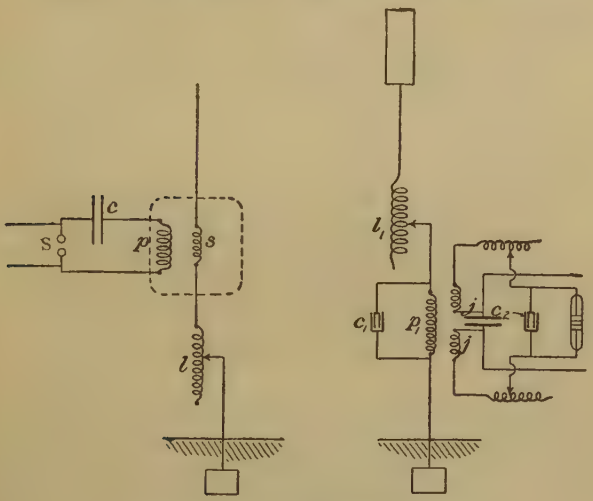


Fig. 145 —Marconi's syntonic system.
(*After Fleming.*)

of tuning appliances. The antenna is a metallic network at the top of a high wire, and contains a coil l_1 with adjustable inductance. Lower down is a primary coil p_1, shunted by a condenser c_1. The oscillations in this antenna are most vigorous when the whole apparatus is tuned for the waves coming from the transmitter. The secondary coil of p_1 is formed in two halves j, j, with a condenser c_2 between them. The coherer is

seen on the right, the relay and Morse instrument being omitted.

Directed Waves.—Hertz reflected waves from mirrors of various types. A plane or flat sheet of metal reflected them in the same way as an ordinary mirror reflects light. By using a parabolic mirror (sheet metal) he obtained a "beam" of waves which travelled only in one direction, as suggested in Fig. 146.

This is a good method for directing the waves, but

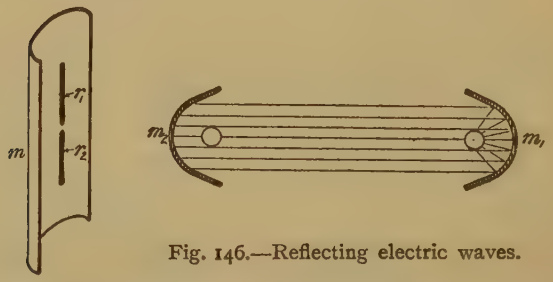


Fig. 146.—Reflecting electric waves.

it is only practicable for small radiators and receivers. The transmitter consists of two short brass rods r_1 r_2 set in a vertical line and fixed in the focal line of the mirror m. When the spark passes, the waves are reflected from m_1 at one end to m_2 at the other, where a converse process takes place. The parallel rays fall on the mirror, where they are reflected to the receiver, and can be detected by using a coherer in the same way as in other apparatus.

As the mirror has to be considerably larger than the radiating apparatus, it is obvious that large scale apparatus cannot be employed, and efforts at directing the waves have turned in other directions. One way is to bend the radiating conductor or aerial. Fig. 147

suggests the simple idea: T is the transmitting and R the receiving aerial. The aerial is *bent back*—that is, away from the direction in which the waves are to go. This gives a directed wave, and is a partial solution of the problem. If the receiver be rotated on the vertical part as a pivot its sensitiveness to signals diminishes. It is therefore possible to tell from what direction the waves are coming; all that is requisite is to turn the bent aerial till the received signals have their strongest value. The bent part is then pointing away from the sending station. This promises to be useful to ships in a fog, for they may receive signals from shore by means of etheric waves, and can tell by the foregoing agency the direction from which the waves come.

Fig. 147.—Aerial for directing the electric waves. (*After Fleming.*)

Transatlantic Telegraphy.—We need only indicate the method adopted. In Fig. 148 the transmitter is seen to be a huge inverted cone or pyramid made of wire. The upper parts are supported by four tall lattice towers T, T, each 210 feet in height. An induction coil does not supply enough power for this huge radiator, and it is therefore replaced by a large dynamo giving alternating currents. By means of a transformer and other arrangements, more or less like those in Fig. 145, the pyramid is raised to a very high pressure, and when the spark passes a powerful radiation takes place. A similar pyramidical aerial serves for the receiver, the connection to earth, etc., being roughly like that of Fig. 145.

In the middle of December, 1901, Mr. Marconi received signals of a tentative kind, and a year later he announced definitely that he had established wireless communication between Cape Breton and Poldhu in Cornwall. Messages were sent from the Governor-General of Canada to the Kings of Italy and Great Britain.

In journeying across the Atlantic during 1902 a very curious fact was observed by Mr. Marconi. He found that signals could be received at a greater distance by night than by day. Under otherwise similar conditions the receiver ceased to respond at a distance of 700 miles in the daytime, although 1,550 miles could be traversed in the night. Mr. Marconi attributed this difference to the effect of sunlight on the transmitting aerial. He believed that the light prevented the radiated waves from being as energetic by day as they are at night. To get much energy the radiator must be raised to a very high pressure before it discharges, and the sunlight starts the discharge at the spark gap at a lower pressure than would suffice in the dark. It ought to be stated that some kinds of light (violet light, etc.) are known to produce an action of this kind.

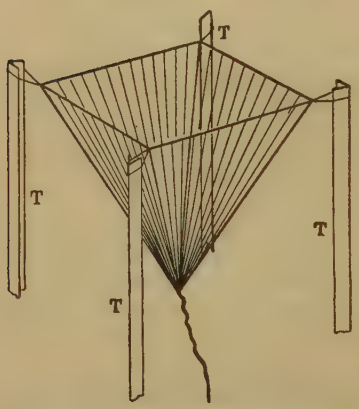


Fig. 148.—Inverted cone aerial for Atlantic telegraphy.

But Professor J. J. Thomson has suggested that

sunlight may produce a lot of negative electrons in the atmosphere, and that these may partially absorb the waves and thus prevent many of them reaching the distant receiving station.

It is known also that the atmosphere gets into certain conditions in which it cannot transmit electromagnetic waves so readily. Lightning discharges and other electric phenomena appear to have something to do with some of these variations, though there may be other causes at work.

Poulsen's System of Etheric Telegraphy.—Something has been said about syntonic telegraphy, and the explanations given will enable the reader to understand that its success depends on accurate "tuning" of the radiator and the receiver. The systems we have so far described do not, however, permit of any great refinement in this respect. They all depend on a spark discharge, which, as we have seen, is an oscillation discharge. Its fault for timing is the very small number of vibrations set up by each spark. They are few in number, and they rapidly decline in strength or intensity. In other words, they are rapidly damped out by the losses incidental to the surging to and fro. Fig. 149 gives a rough picture of what is meant. The intensity of each wave diminishes, is less than that of its predecessor, and becomes zero at the end. This is what follows each spark. After this comes an interval, and then a second spark with the same oscillation, and so on. At the first glance we are inclined to think that one spark must follow quickly after the oscillation of the last, but it is not so. The interval may be 1,000 times as long as the oscillations. A spark and its oscillation may last $\frac{1}{100,000}$ of a second, and the interval may be a much larger fraction, say $\frac{1}{50}$. With such a jerky kind of radiation, tuning of

the transmitter and receiver is not very accurate, and the value of syntonic working is therefore diminished.

To meet this difficulty Herr Poulsen has developed a method of producing continuous vibrations in the ether. The results obtained show that each signal consists of a series of undamped waves (Fig. 149*a*) whose difference from those produced by a spark gap series is very great. We must be content to indicate the general nature of the method. A preliminary word

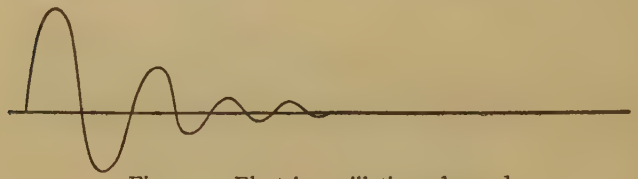


Fig. 149.—Electric oscillations damped.

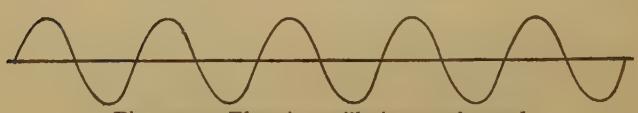


Fig. 149*a*.—Electric oscillations undamped.

must be spoken about what is known as the musical arc.

The Musical Arc.—If a battery of accumulators is connected through a resistance to two carbons, which are made to touch and then separated by a short distance, an arc is formed in the usual way. If certain additional apparatus be joined as a shunt to the arc a musical note is heard. This additional apparatus consists of a condenser and a coil of wire. The one adds capacity, the other inductance, and the vibrations obtained depend on the value of these.

Poulsen's Use of the Arc.—Herr Poulsen modifies this arrangement. First, he uses carbon for the

negative pole of the arc only; the positive pole is made of copper, kept cool by a flow of water through an internal hole, or by flanges which expose a large surface to the air. Secondly, he encloses this arc in a gas-tight box, through which he passes a current of hydrogen or coal-gas. The current also passes through an electromagnet fixed near the arc, which is thus fixed in position. Under these conditions it is necessary to use a pressure of 120 volts; the current is about 10 amperes.

Poulsen's arrangement of the arc for etheric telegraphy varies somewhat. One form is shown in Fig. 150. The wires w_1 and w_2 come from the positive and negative terminals of a dynamo or battery,* and are connected to the two sides of the arc a. From the lower (carbon) electrode a wire is taken to a condenser c_1 and from this to the lower end of an inductance coil L. The upper (copper) electrode is joined to a condenser c_2, whose further terminal runs to a movable contact point p by which more or less of the coil L can be included in this branch circuit. The upper end of L is connected to the aerial line, while an adjustable earth contact touches another part. When these arrangements are completed a persistent electric oscillation or surging is set up in L and c_1 c_2,

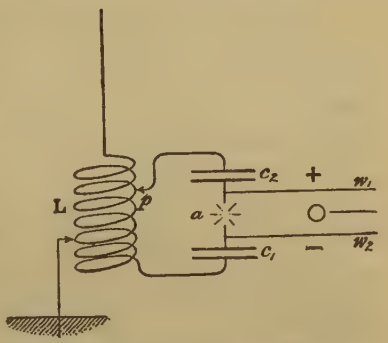


Fig. 150.—Poulsen's transmitter for undamped waves.

* The mains from a public supply authority may also be used.

while a powerful train of waves is radiated from the aerial.

By adjusting the capacity of the condenser or by altering the number of turns of wire in L, the rate of vibration can be altered at will, and in this way the apparatus can be tuned.

Poulsen's receiver is indicated in Fig. 151 : *a* is the aerial, c_1 a condenser shunted by the primary coil *p* of a transformer. The aerial is continued down to an earth plate E. The secondary coil *s* is connected to a telephone and also to condensers, as indicated in the diagram. Tuning is done by altering the capacity of the condenser c_2 till receiver and transmitter agree.

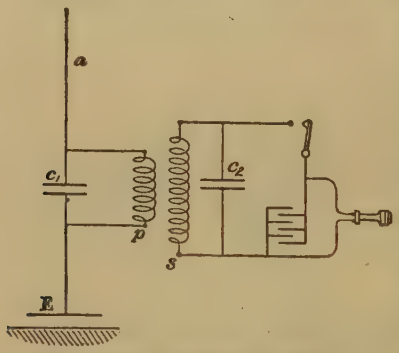


Fig. 151.—Poulsen's receiver.

It only remains to indicate how the signals are made at the sending station. The method varies. One way is to have a key joined by wires with two points in the coil L of the transmitter seen in Fig. 150. Waves are being emitted from the transmitter, these having a definite frequency or period. But this period is not of the right order to act on the receiver. The effect of the key is to alter the number of effective turns in the coil, and so to bring its vibration time into harmony with the receiver, thus producing a signal at once.

CHAPTER XI

ELECTRIC MOTORS

An electric motor is almost the same as a dynamo in general construction. There is a field magnet (with two, four or six poles), an armature, a commutator, and two or more brushes. For the general meaning and action of these we can therefore refer to the sections on "How a Dynamo is Made" and "How Dynamos do their Work," in Chapter II. Two or three points of difference in detail may be mentioned. A great many motors are now more or less "enclosed," that is, the active parts are covered by an iron case. Three varieties are commonly spoken of: an open-protected motor, a semi-enclosed motor (partly shown in Fig. 152, Plate II.), and a totally enclosed motor (fully shown in Plate III.).

Another difference arises out of the fact that the parts of a motor may have to stand violent mechanical forces. Hence the wires or bars used for armature conductors are most frequently embedded in slots, so that they cannot be dragged out of position by the forces acting on them.

Again, a motor armature may require to have its motion reversed, which never happens to a dynamo. To facilitate reversal the brushes are made of carbon and have a fixed position, pressing directly on the commutator. This is shown in Fig. 153.

The essential difference between a motor and a dynamo lies in their relation to forms of energy.

A dynamo receives power in a mechanical form and converts it into an electrical form.

A motor receives power in an electrical form and converts it into a mechanical form.

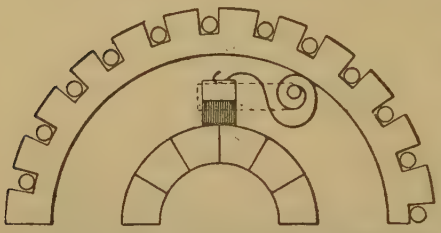


Fig. 153.—Motor armature conductors in slots. Carbon brush pressed on commutator by a spring.

The action of one machine is a reversal of the other, and it is this which makes the two so very useful in distributing power over long distances. In this respect they are unique.

The point, however, which astonishes most people is the unknown way in which a motor is able to exert "force." We shall say a few words on this.

Origin of Mechanical Forces. — In ordinary machines, forces are transmitted by belts or chains or wheel gearing. In an electric motor these do not exist. Yet on the basis of data already given it is easy to explain this. A mechanical force arises whenever an electric current passes across a magnetic field —that is, in front of a magnetic pole.

The peculiar feature of this force is the direction in which it acts. It is not in the direction of the current or of the magnetic field, but at right angles to both. To explain this Fig. 154 is drawn to include all ordinary cases. A magnetic pole is shown with a conductor crossing it. In *a* the pole is north, so that the field of force is directed towards the reader. In *d* the field is directed away from the reader. Side views of these are given in *b* and *e*. In each of these

the current is passing away from the reader (as shown by a cross), and the mechanical force is indicated by the arrows. In *b* it acts downwards; in *e* it acts upwards. This reversal is due to the fact that the current passes through the two magnetic fields in opposite senses. In *c* and *f* the currents are approaching the reader (as shown by central dots in the wire), and the mechanical forces act upwards in *c* and downwards in *f*. This reversal again arises from the magnetic fields

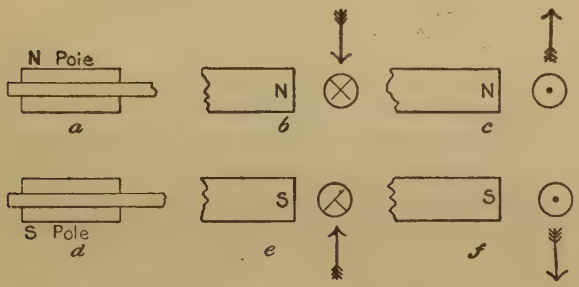


Fig. 154.—Mechanical forces arising from currents flowing through magnetic fields.

being oppositely directed. But now compare *c* with *b*. Here the magnetic fields are in the same sense (from left to right), but the currents are reversed. This gives rise to a reversal of the mechanical force. Lastly compare *f* and *b*. Here the magnetic fields are reversed and the currents are reversed, with the result that the mechanical forces are in the *same* direction—both downwards.

The force can thus be reversed either by reversal of current or of magnetic field. If *both* fields and current are reversed the force continues in the same direction.

So far we have merely stated the facts; the explanation of one case will illuminate them all. In Fig. 155*a* the field of the magnet is indicated; in Fig.

Fig. 155.—Combination of fields.

155*b* the field due to the current. Although the latter is a circular field, we may notice that at the top this means that its direction is from left to right, *agreeing with the field of the magnet;* while below the circular field is from right to left, contrary to the field of the magnet. Consequently the two fields amalgamate above the wire and produce a stronger field; below it they produce a weaker field, because they are antagonistic. The result is seen in Fig. 155*c*, where the secret of the mechanical force is revealed. The crowded lines above the wire repel each other and also repel the current which is squeezing them so close together; the latter is therefore driven downwards.

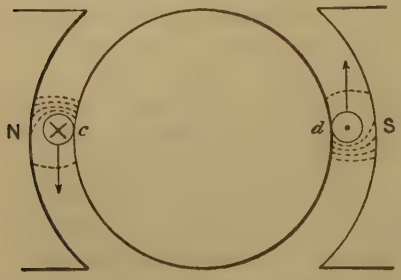


Fig. 156.—Forces acting on armature conductors.

By a little careful thought the other cases will be

easily understood. Let us apply this now to the case of an armature, taking first the case of two conductors, *c* and *d*, as in Fig. 156. The field of the magnet is from left to right on both sides; that of the current in the conductors is in each case circular, and has a clockwise direction on the left, anti-clockwise on the right. The conjoined fields are indicated, and the resultant mechanical forces are shown by arrows. Clearly these will act together so as to give a rotatory motion in an anti-clockwise sense.

Apply this now to an ordinary armature, where there will be many conductors. All those under the N pole will be like the one shown in Fig. 156; they will have the current flowing away from the reader, and the mechanical force will act downwards. On the other side, seeing that the current there flows towards the reader, the force will act upwards; all the separate forces will urge the armature round in the sense indicated—anti-clockwise.

The Strength of the Forces.—The strength of the force depends on three things:—

(*a*) The intensity of the magnetic field, or, in other words, the close packing of the magnetic lines;
(*b*) The strength of the current;
(*c*) The length of the conductors carrying the current, only that part of their length which is in the field being counted.

These values are often great enough to create a force of 5 lb. on each conductor. That being so, the force due to all the conductors may be very considerable and quite enough to account for the energetic action of a motor under practical conditions.

Series and Shunt Motors.—These names refer to the way the field magnets are excited. If the whole

current given to the motor passes round the field-magnet coil it is a series motor (Fig. 157*a*). If the current entering the motor divides between the armature and the field-magnet coil it is a shunt motor (Fig. 157*b*). The series motor is in some ways simpler than the shunt. It is suitable for vehicles, because it will work well at different speeds, giving strong forces when at rest or at low speeds, and taking less current when speeds are high and steady.

A Series Motor and its Speed.—This is the type used for vehicles, motor-cars, tram-cars, etc. Fig.

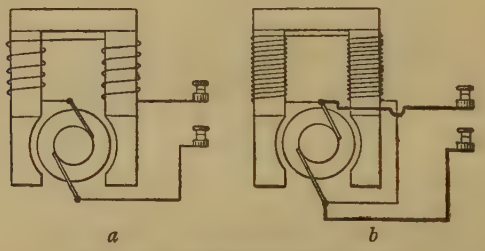


Fig. 157.—Series and shunt motors.

158 (Plate III.)—for which we are indebted to Prof. Walmsley's "Electricity in the Service of Man"—gives an idea of the outer appearance of a tram-car motor. It is a 4-pole motor, so that its magnetic system resembles Fig. 32 (page 41) rather than Fig. 157, the whole being concentrated as much as possible because of the limited space under the car.

The behaviour of a tram-car or other series motor depends on the electric pressure urging a current through it. Starting with the motor at rest, and switching on to a suitable dynamo or battery, a strong current flows, too strong for safety in many cases. The strong current gives a full magnetisation of the

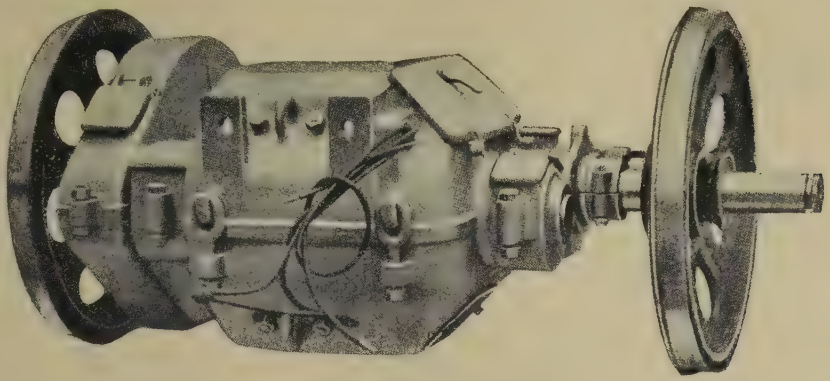


Fig. 158.—Preston tram-car motor and running axle.—*See p. 258*

magnets, and therefore the mechanical forces are very powerful. This is just the condition required for starting the car into motion, always the heaviest work the motor has to do.

A strange thing happens as the car gets up speed: the current begins to diminish. It may have been 50 amperes while the armature was at rest; it may now fall to 20 or less. The reason for this is curious. Let us suppose that the voltage put on the motor is 100. This will produce a certain current, according to the resistance of the motor. The armature begins to rotate, but, as soon as it does so, it acts not only as a motor but as a dynamo as well. That is to say, it develops an electric pressure or voltage of its own, and the special feature of this pressure is that it acts against the current, tending to stop it, but failing to do more than reduce it. This reverse voltage developed by the motor may be 80 volts. Thus we have 100 volts urging the current forward, 80 volts urging it back, so that there are only 20 volts actually available for pushing the electrons through the conductors. The 80 volts (or any other value which the motor produces) is called the back electromotive force of the motor. It is developed only when the armature is rotating, and increases with the speed and the magnetisation. We have said that the current which flows when the unmoving armature is switched on may be too strong. The reason is that the motor has (generally) a small resistance, and the current therefore is strong and has a large, perhaps a dangerous, heating effect. But as the motor gets up speed its back voltage cuts down the current to a safe value, and so saves the armature from burning out. It is important, therefore, to keep the current in check till some degree of motion is established. A few words on

the method of doing this on a tram-car will be helpful. We shall suppose that the line is one that has a trolley wire suspended over the middle of the street. This carries the current to the cars, each of which is equipped with a trolley pole P (Fig. 159). The current flows through the motors, etc., and passes on to the running rails, that is, those laid on the street. These are in 30-ft. lengths, but are connected together by stout copper bonds. The supply station keeps the trolley wire at a pressure 500 volts above the rails.

Tram-car Motors and their Controller.—A tram-car is equipped with two motors and a controller or

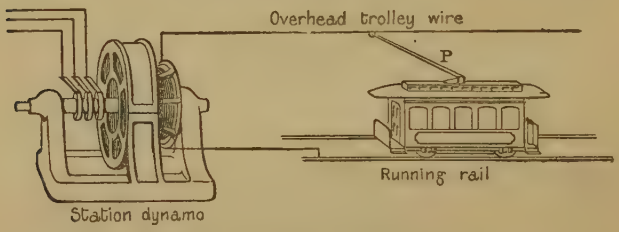


Fig. 159.—Method of running a tram-car.

regulator. The driver can work this controller so as to get a great variety of speed, its action being to alter the connections of the two motors and a resistance. When the driver brings the handle of the controller to the first notch, he connects the motors in series with a resistance, as seen in Fig. 160*a*.

M_1 M_2 are the two motors, R is a resistance of stout wire all joined in series, T is the overhead trolley wire in the middle of the street, E is the return conductor by which the current gets back to the supply station. With the arrangement shown in *a* the 500 volts have to urge a current through the resistance R as well as the two motors, these last being at rest. There is no back

voltage to keep down the current, which has consequently a high value. The strong current and strong magnetic field give an enormous pull to the motor gear, and the car starts. Its movement creates a back electromotive force, increasing with the speed, and so diminishing the current. When a certain speed is attained the driver moves the handle to the next notch, short-circuiting or cutting half the resistance R out of circuit (Fig. 160*b*). This restores the current, raises the speed and the back voltage, and so the current falls again. The next notch (Fig. 160*c*) cuts out the resistance altogether. The fourth notch puts it all in again, with the two motors in parallel. The fifth notch takes out half R, and the sixth removes the whole, so that each motor is now independently connected to the trolley wire T and the rails E, and is therefore being run at 500 volts. The current through each would now be destructive if it were not that speed is up and the back pressure of high value, possibly 450 volts. With this check the current is much less than at the start, but the power required now that speed is up is also much less than that needed to establish the motion.

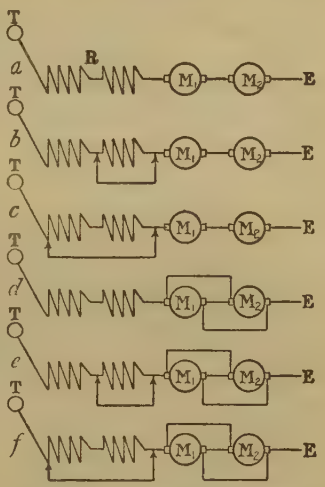


Fig. 160.—Action of motor controller.

The car is stopped by taking the handle of the

controller back to zero position, which of course breaks the circuit. This cuts off the power, and the brakes stop the car. If necessary the motors can be short-circuited, and they then act as an additional and most powerful brake. The controller contains an arrangement for magnetically blowing out the sparks which occur when the many inside contacts are broken.

Reversal of a Series Motor.—This is brought about by reversing the current in the armature, leaving the field magnet current to flow in the same direction. Fig. 161 shows the general idea: M is the motor and

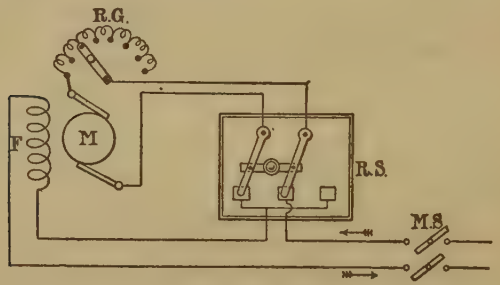


Fig. 161.—Reversing switch for series motor.

F the field magnet. The reversing switch R.S. can be reversed by moving the handles to the right or left. This reverses the current in the armature, leaving it as before in the field. A regulating resistance R.G. is inserted so that the change in value and direction may not be too sudden: M.S. is the motor switch proper. Before M.S. is put on, all the resistance in R.G. ought to be in circuit, but can be removed as the motor gets up speed.

Electric Automobiles.—These are usually equipped with two motors M_1 M_2 and a controller similar to that

described, but smaller. A battery of 44 accumulator cells is provided, giving an electric pressure of 88 volts when in series or 44 volts when split in two and the halves joined in parallel. The following is one way of controlling the speed.

At the first notch of the controller the accumulators are in parallel and the motor in series, as in Fig. 162, where two groups of only four cells are shown. Other notches put the cells in series (doubling the pressure), arrange the motors in parallel (again doubling the pressure on each motor), and also put the field magnet coils in series or parallel. Each of these changes gives a different speed.

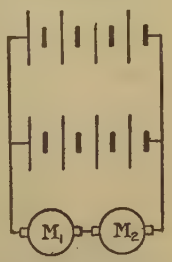


Fig. 162.—Automobile battery in parallel, joined to two motors in series.

The weak part of an electric automobile is the battery. Accumulator plates are not mechanically strong, and the jarring they receive on the road soon weakens them, though careful attention may defer the inevitable breakdown. Edison and others have tried to produce a more trustworthy accumulator than those now used, but their work is not yet ready for public service.

Shunt Motor.—Ordinary machines, like lathes, printing machines, planing machines, etc., make demands which are very different from those of a vehicle. They want a regular speed, and starting and stopping are comparatively rare. Imagine the case of a planing machine. When the cutting tool is at work the force required to drive the machine is very great; as soon as the cut is complete the requisite force is small. If driven by a series motor the speed would change enormously. A motor is required which will more or less

automatically adapt itself to these and similar changes of load, and this is found in the shunt motor.

Its peculiarity is this: the armature and the field-magnet coil are joined to the mains independently. Consequently the current passing through one of them may change while the other remains constant. This is impossible with the series machine, and out of this

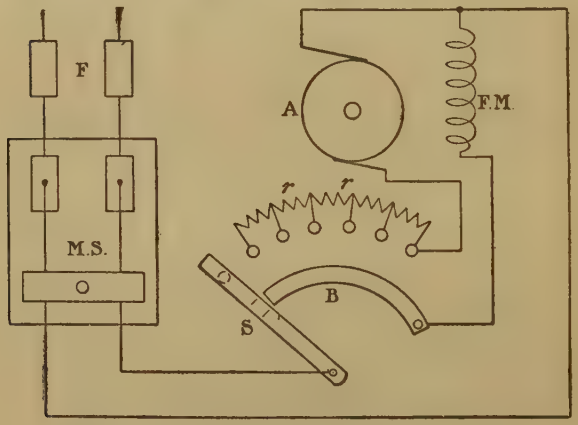


Fig. 163.—Regulating switch for shunt motor.

difference many others grow. Fig. 157*b* (page 258) shows a diagram of the machine, and Fig. 163 is a simplified sketch of the connections. Besides the fuses F, there are two switches; a main switch M.S. and a starting switch S. The main switch is put on first; S is then moved *slowly* over the stops. The motor is not joined to the mains till S begins to move; its first effect is to touch the metal arc B, and so start the field magnet current F.M. As S is carried farther, it connects the armature A also to the mains, but at first through the regulating resistance *r r*. As S moves farther on, it

cuts out more and more of the resistance, and finally joins the armature directly on to the mains. These successive movements of s are guided by the increasing speed of the motor. It is imperative that *r r* should not be cut out till fairly high speed is attained.

To prevent accidents a "starter" for shunt machines is provided with two automatic releasing arrangements, one of which may be sketched. Imagine

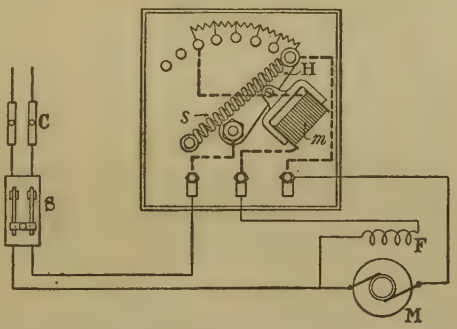


Fig. 164.—Safety arrangement for shunt motor. "No volts" release.

a shunt motor running well at full speed, all resistance out, starter full on. Now suppose that the main switch is opened for a moment, or that the dynamo fails for a little while. There is then no pressure on the motor terminals and the current ceases: it is a case of "no volts." The starter handle, however, remains over, and the armature is joined dead on to the mains, although it is at rest. Now let the pressure be resumed, that is, the dynamo works again or the main switch is put on. Immediately the armature will be burned out, because of the enormous current that will flow.

To avoid this the handle is attached to a strong spring, which always pulls the handle to the "off" position as soon as the field magnet loses its excitation. As long as it is excited its current also excites a small electromagnet which holds the handle in the "on" position. Fig. 164 shows the arrangement: *m* is the magnet through which the field current flows. If voltage ceases *m* loses its ability to hold the handle H, and the spring *s* drags the latter off. The arrangement of the diagram gives an idea of the usual adjuncts: C is a double cut-out or fuse; S is a double-pole switch; M is the motor armature and F its field coil.

Regulating Speed of Shunt Motor.—This is very often done by having a regulating resistance in the field magnet circuit. A handle enables the man in charge to put more or less resistance in series with the exciting coil; he can in this way increase or diminish the exciting current. Reducing the magnetising current increases the speed. The reason for this is not easy to explain. Suffice it to say that when the magnetisation is reduced the back pressure of the motor falls and allows a stronger current to flow. This increase in the current is relatively greater than the fall in the strength of the field. A 5 per cent. reduction in magnetisation may mean 30 or 40 per cent. increase in current. Consequently the motor increases its speed till the current is readjusted so as to maintain it.

Other Traction Systems.—Nearly all tramways are worked on the system shown in Fig. 159 (page 260). An overhead wire carries current to the car, the running rails conduct it back. In a few cases a tunnel is made underneath the ground between the running rails, and contacts are arranged with the two mains which bring

Fig. 165.—Westinghouse single-phase locomotive and train.—*See p. 267*

the current to and from the generating station. A slot in the surface gives access to the contacts below, and through this passes a plough fixed to the tram-car. The lower end of this plough has two contact pieces which touch the main conductors in the tunnel; its upper end is joined to the motors and the controller. As the car moves forwards the plough goes with it, keeping it in touch with the mains. Hence the supply of power is obtained without appreciably altering the look of the street, as the trolley system does.

For longer distances than those covered by ordinary tramways, higher pressure than 500 volts is exacted by economic considerations, and an alternating current must be employed so as to get rid of commutator troubles. The explanation of these points must be sought in more advanced works. A view of the Westinghouse single-phase locomotive, etc., is given in Fig. 165 (Plate IV.).

Large Generators.—Electric dynamo generators do not always take the form described in Chapter II. Very large generators are made in which the magnet is like a huge fly-wheel, with many alternate poles projecting from its circumference. The armature coils are then wound on the inner face of a larger wheel, which just encloses the fly-wheel magnet. Here, the magnet revolves, the armature is at rest; in other words, the magnet fields are successively dragged through the armature coils. The currents obtained are alternating. Fig. 166 (Plate V.) gives a view of part of one of these fly-wheel magnets, but the details are beyond the scope of this book.

Niagara.—We propose to conclude this section by giving some account of the way in which the Falls at Niagara are utilised for producing electric energy. The frontispiece to this book gives a general view of the

position, and may be examined with profit. The water is taken from Niagara River above the Falls by a canal running from the river through the town. At the end of this canal is the power-house, P. Under its roof are the wheel-pits, containing the penstocks and turbines (horizontal water-wheels). The water falls through W to the turbine T at the bottom, and then passes away by a long tail-race T R, and reaches the river below the cataract. Fig. 167*a* gives some idea of the arrangement, P being the penstock down which the water falls; T is the turbine whose internal blades are driven round by the water; T.S. is the turbine shaft carrying the power to the dynamo D at the top. The length of the turbine shaft is about 140 feet, and as it is a steel tube 38 inches in diameter its weight is obviously very great.* Moreover, it carries round with it the heavy field magnet system of the dynamo at the top. Even this revolving part weighs nearly 80,000 lb., and the total weight of the revolving shaft and magnet is not far short of 200,000 lb.

The pressure of this enormous mass threatened to produce a very serious amount of friction at the step on which it rested at the bottom, but this was overcome by an ingenious device. The penstock P curves into the turbine from the bottom, and the water is thus given an upward turn as it meets the blades, etc., of the turbine. Its effect is so great that it practically neutralises the effect of gravitation, and the shaft with the magnet at the top is almost floating on a watery support.

We shall briefly describe the dynamos as they were first installed. They are designed to give alternating

* The shaft is not in one piece, and at several places it has to be enclosed by bearings and guides. At these places it is solid and 11 inches in diameter.

Fig. 160.—Magnet wheel of Greenwich generator: side plates riveted on; fixed coils in position.—*See p. 267*

currents, so there is no commutator. The field magnet revolves at the top of the turbine shaft, and has roughly

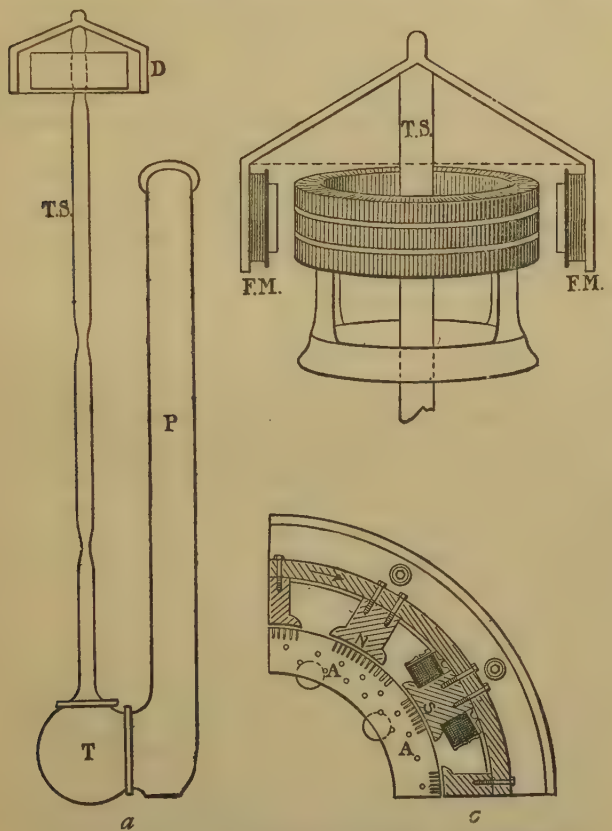


Fig. 167.—Sketch of turbine and dynamo at Niagara.
(*After Cassier's Magazine.*)

the appearance of a great umbrella, as can be seen at D (Fig. 167*a*). It is shown in diagrammatic form in

Fig. 167*b*: F.M. is the field magnet ring, with 12 pole pieces projecting inwards. The armature is *fixed,* and is indicated by A (Fig. 167*c*). The vertical shaft of the revolving magnets passes through the middle of the armature. As the poles pass the armature conductors the flux produces an alternating pressure of 2,000 volts, the speed being 250 revolutions per minute. By combining Figs. 167*a*, 167*b*, and 167*c* a very fair idea of the arrangement can be obtained.

When Niagara Falls were first called on to supply electric energy, ten turbines were to share the work, each giving 5,000 horse-power and working at 2,000 volts. The total therefrom came to 50,000 horse-power.

This power was distributed to many customers. One company required 2,000 horse-power for producing aluminium (page 142). A carborundum company took 1,000 horse-power, and so on. Fifteen hundred horse-power was used in working the trams to and at the town of Buffalo, nine miles away from the Falls. These figures will give some idea of the way in which the power is used, but the many interesting problems which were solved are beyond the scope of this work.

The ten turbines used 4,300 cubic feet of water per second. This is 260,000 lbs. of water, and it was the fall of this through 136 feet that supplied the energy to raise 18,600 coulombs through 2,000 volts every second.

The electric energy can be supplied to large customers at a very low rate, in some cases at less than $\frac{1}{10}$ of a penny per Board of Trade unit. In fact, in several towns lying within 40 or 50 miles of the Falls it is cheaper to take power electrically from the Falls than to rely on coal and use engines,

boilers, and all the other usual adjuncts of steam-power.

Ignition Sparks for Petrol Engines.—A brief explanation may now be given of the way in which electricity is used to explode the working vapour in the cylinder of a gas or petrol engine. The barest sketch must suffice. In Fig. 168 S.P. is the sparking plug fixed in the cylinder walls, with the two points

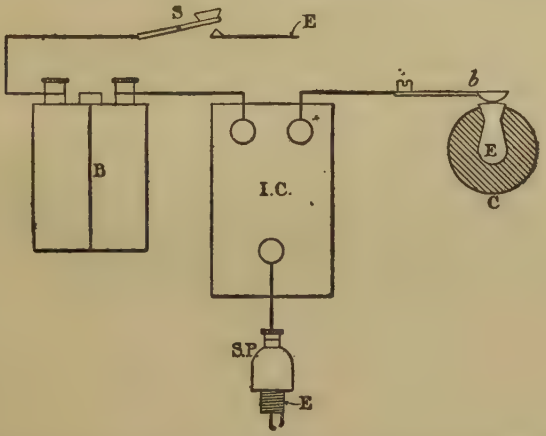


Fig. 168.—Battery, coil, contact and sparking plug used in igniting petrol mixtures.

projecting into the chamber. The middle point is connected to the secondary terminal of an induction coil I.C. The letter E indicates a connection to the framework of the car. The battery B sends a current through the primary winding of the coil, but can only do this when the circuit is complete. Suppose the switch S is put on, there may still remain a break at the commutator C. This is an insulating disc, one part of which is replaced by a conducting

segment (shown unshaded). This commutator is fixed on the half-speed shaft of the engine, and the segment makes contact with the ironwork of the car. Once every revolution this segment makes contact with the metallic blade *b*, and thereby completes the primary circuit. At this moment (and only at this moment) the battery can send a current and excite a high voltage in the secondary coil, and therefore a spark passes.

It is easy to see that the moment of contact of blade and segment can be altered by rotating the disc, and thus the moment of sparking can be adjusted to the requirements of the engine or its driver.

There are many other applications of permanent interest, just as there are many installations of peculiar ingenuity, but enough has been said to give the reader some idea of the boundless resources of electrical engineering.

CHAPTER XII

RÖNTGEN RAYS AND RADIUM

Röntgen or X-Rays. — In the year 1895 Professor Röntgen, of Würzburg, while studying the effects produced by sparks in highly exhausted tubes, discovered that they emitted something beside greenish-yellow light. He covered the vacuum tube with black paper so that his eye could detect neither spark nor phosphorescent light. Yet when he brought near some crystals of a substance known as platinocyanide of barium these began to glow in a most remarkable way. It was evident that the vacuum tube was radiating some kind of invisible and unknown rays.

These Röntgen rays are now produced by using an induction coil like that described in discussing wireless telegraphy and pictured in Fig. 19 (page 20) and Fig. 139 (page 231). The vacuum tube is given the form shown in Fig. 169, where the terminals are marked N and P : N ends in an aluminium cup, P in a platinum plate : N is connected to the negative and P to the positive terminal of the secondary coil, so that the cathode rays or electrons (*see* page 22) are shot from the cup-shaped cathode in a beam converging on the positive plate in front, this being generally called the anti-cathode. The electrons fly with immense velocity (thousands of miles per second), and, falling on P, are brought to a stand in an exceedingly short time.

It is this collision of the electrons with the positively-charged anti-cathode which produces the Röntgen rays. The sudden stop gives rise to a shock or

pulse in the ether, just as the sudden stoppage of a bullet by a target gives a flash of light. When we remember how much greater is the speed of the cathode rays, we cannot be surprised to find that they, too, give a "flash" of something when they are abruptly brought to rest by the platinum anti-cathode.

The pulses given out by Röntgen rays are not, however, like a flash of light. They can penetrate where light is unable to go. They pass through wood,

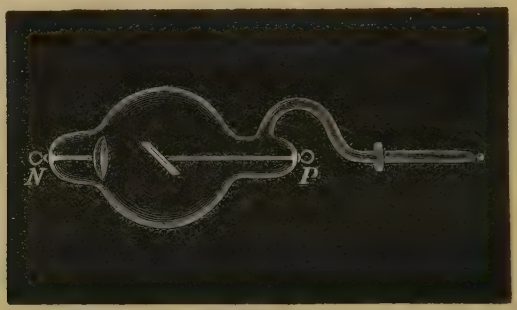


Fig. 169.—Focus tube for producing Röntgen rays.

oil, thin metallic sheets, and all organic tissues. But in passing through these substances they are more or less absorbed; the substances are not equally transparent to them.

Gold and silver are less transparent than aluminium, and aluminium is less transparent than wood; bones are less transparent than flesh. When Röntgen rays are allowed to fall on a cardboard screen, whose remote side is covered by platinocyanide of potassium, they set up a bright phosphorescence, so that in a dark room the screen looks like a sheet of light. Now if any substance is interposed between the focus tube and the screen it absorbs some of the rays and the screen shows

Fig. 170.—Shadow of hand cast by Röntgen rays.—*See p. 275*

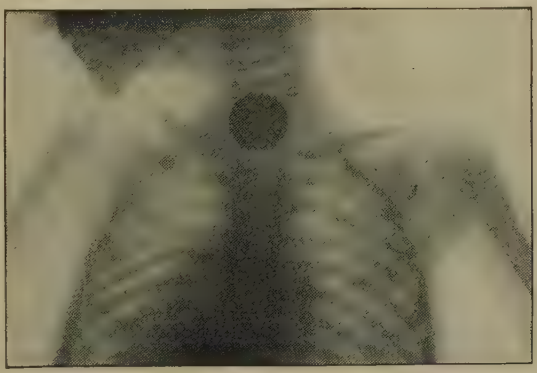


Fig. 171.—Shadow of a boy's chest showing a swallowed coin.—*See p. 275*

a shadow. If the hand be interposed a shadow is cast by both flesh and bones, that of the flesh being very slight, that of the bones much darker. Hence to anyone looking at the bright screen the bones appear in darker outline on the slighter shadow of the flesh, and a man appears to "see his own bones." He is, of course, looking at the shadow cast by them when Röntgen rays pass through his hand.

Shadows of other things can also be seen. If a needle has entered the flesh it casts a shadow denser than flesh, and can therefore be seen as a black mark even against the dark bones. Thus by using Röntgen rays and a phosphorescent screen a surgeon can discover the presence and locality of a metallic or other body which has entered the flesh of a patient.

He then takes a photograph to localise the intruder more exactly. Röntgen rays affect the photographic film very much as light does, and the "shadowgraphs" obtained are of daily service in medical practice. Plate VI. (Figs. 170 and 171) shows examples of these shadow photographs.

Although akin to ordinary light, Röntgen rays exhibit some considerable differences. They cannot be reflected by a mirror, or refracted (bent) by water or similar bodies. When they are absorbed by any substance they give rise to a peculiar secondary action, too abstruse for us to discuss here.

It has been found that Röntgen rays act on the skin. They often have a seriously dangerous effect on the hands of the operators, giving rise to wounds that are difficult to heal. These dangers are only felt after prolonged and repeated exposures, and therefore do not hurt the patient. On the other hand, the same rays have been found to have a beneficial and even curative effect on certain forms of skin disease.

Radium.—In connection with electrons a word may be said about radium. This is an element of metallic nature which has not yet been obtained in the metallic state. It is prepared as radium chloride or bromide from a mineral known as pitchblende. It may fairly be included among the electrical substances, for a careful examination shows that it gives off the following different things or "rays":

α rays: positively charged atoms of matter.
β rays: electrons or corpuscles of negative electricity.
γ rays: apparently the same as the Röntgen rays described in the last section.

The simple substance known as radium bromide is therefore able to do without any apparatus what we accomplish by means of battery, induction coil, and vacuum tube. The theory of radium is roughly this: Its atoms are undergoing a kind of electric disintegration. Like other elements, its atoms contain many electrons, and radium is constantly throwing some of these off. These are the β rays. By doing so it loses negative electricity and leaves a residue of positively charged atoms, which fly off; these form the α rays. The third kind of rays is formed in the bombardment arising from the others. Another peculiarity of radium is that it is continually giving off heat, though this is probably a consequence of its atomic disintegration.

One of the most important and most difficult questions about the disintegration of radium is this: Does it split up into any other elements? The evidence seems to give an affirmative reply to this question, but it is not universally accepted as conclusive.

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